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Surface-Water and Groundwater Interactions of a Stream Reach and Proposed Reservoir within the Pascagoula River Basin: George County, Mississippi

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Surface-water and groundwater interactions of a stream reach and proposed reservoir within the Pascagoula River Basin: George County, Mississippi

By

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This research had two main objectives: quantify surface-water and groundwater interactions along a stream reach, and determine the hydraulic conductivity at the site where two reservoirs are proposed. The objectives of this research aim to help maintain stream ecology and increase surface water storage for recreational and industrial purposes. The stream reach, located in the Pascagoula River Basin of southeast Mississippi, begins at Lake Okatibbee and terminates at Pascagoula into the Gulf of Mexico. Four USGS continuous gauging stations provided more than forty years of stream discharge data for a hydrograph base-flow-recession analysis, which determined the baseflow component within the stream. The analysis showed that baseflow decreases along the stream reach and increases again before reaching the Gulf of Mexico. Thirteen borehole samples were collected at the sites of the proposed reservoirs in George County, Mississippi to determine the hydraulic conductivity of the sediments, which showed high a hydraulic conductivity.

DEDICATION

This work is dedicated to my parents, James and Kathleen Killian, and to all other close friends and family that have helped and supported me during this adventure.

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CHAPTER I

INTRODUCTION

1.1 Overview

Fresh water accounts for less than one percent of the water on the surface of the earth (McMahon and Mein, 1986). Less than half of the amount of fresh water accessible at the surface and is contained in lakes and streams (McMahon and Mein, 1986). Accurately quantifying the supply of fresh water resources available to meet demand is the motivation for this study. Mississippi uses fresh-water resources for agricultural, recreational, and industrial purposes. This study has two main components: the quantification of fresh-water resources along a stream reach within the Pascagoula River Basin, and the identification of sediment permeability for the storage of fresh water at a proposed reservoir location in George County, Mississippi. The two main components will be referred to as the surface-water and groundwater interactions and reservoir construction throughout this study. Evaporation and evapotranspiration processes are outside the scope of this study.

The quantification of fresh-water resources is important for optimal management of those resources, especially during times of low flow and drought. During low flow, the streamflow is predominantly baseflow, which allows for a better estimation of the quantity of water available (Smathtin, 2001). Baseflow is the water contributed to a stream from groundwater discharge and supplies the stream with water in the absence of precipitation (Newcome, 1967). Baseflow is also a reflection of long-term changes in the groundwater table (Collischonn and Fan, 2013).

1.2 Significance

Historically in the Pascagoula River Basin, water was released from the Okatibbee Reservoir, located upstream, during periods of little to no precipitation to maintain stream ecology and meet water use needs downstream at Pascagoula, Mississippi (Figure 1.2). Toward the end of the year 2000, after a statewide drought, Chevron and Mississippi Power agreed to purchase four billion gallons of water from the Pat Harrison Waterway District (PHWD), which oversees the Okatibbee Lake and water released into the Pascagoula River, to prevent the industries from shutting down (Figure 1.1). The PHWD is the state agency responsible for maintaining the streams and rivers in southeast Mississippi. Chevron and Mississippi Power bought the water at the price of $25,000 for every billion gallons used, as well as $100,000 upfront for the rights to the water within the Okatibbee Reservoir. Not all the water, however, made it to Pascagoula due to possible evaporation or to seeping into the groundwater table. The loss of water sparked interest to gain an understanding of the surface-water and groundwater interactions within the area. The goal of this surface-water and groundwater interactions study is to quantify the amount of fresh water available within the study area, in response to the loss of water purchased by Chevron and Mississippi Power. It is hypothesized that, during times of low flow, a percentage of the available fresh water released from the reservoir is lost to bank storage along the stream reach. This study aims to quantify the groundwater and surface-water interactions within the Pascagoula River Basin to provide information that can lead to better water resource management. The information gathered from this study will help to quantify groundwater and surface-water interactions in other geologically similar areas.

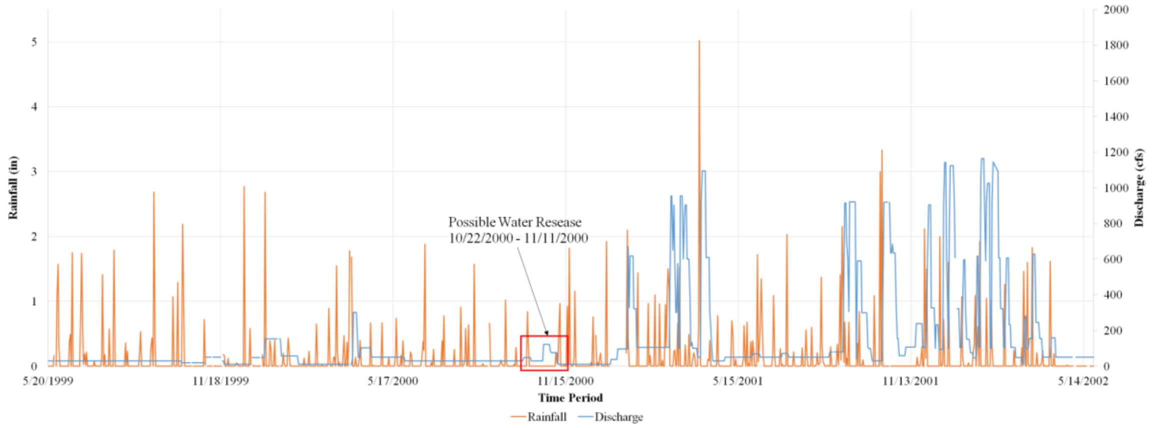


Figure 1.1 Possible water release from Lake Okatibbee

George County, Mississippi, located within the Pascagoula River Basin, has proposed the construction of a reservoir along the stream reach to assist in the management of fresh-water resources in response to the need to maintain stream ecology and meet the water needs of industries downstream. The Pat Harrison Waterway District stated that the creation of the reservoir would benefit the surrounding area by providing a recreational area and supplying water more quickly to the industries downstream (PEER Report #576). A previous study conducted in George County, Mississippi determined the best location for the reservoir (D. Schmitz et al., Personal communication, 2013). The same study also determined that two small reservoirs would be more effective and efficient than one large reservoir (D. Schmitz et al., Personal communication, 2013).

Before the construction of the reservoir, the geology at the site needs to be understood. The hydraulic conductivity was determined from the geology at the reservoir site. Hydraulic conductivity is the capacity of rock or soil to transmit water that is under the influence of gravity. The hydraulic conductivity influences two factors concerning the reservoir. The first is the amount of water that will move to bank storage, and the second is the amount of time needed to fill the reservoir. Rock or soil with a high hydraulic conductivity is highly permeable and will transmit and hold more water than a less permeable rock with a lower hydraulic conductivity. Rock or soil with a high hydraulic conductivity will increase the amount of water held in bank storage as the groundwater table reaches a new equilibrium in response to raising the surface water level. The amount of water held in bank storage influences the amount of time needed to fill the reservoir. Previous studies in the Pascagoula River Basin have reported on the water resources of the area, detailing information including depth to the water table and which geologic units act as good aquifers. This is the first study to attempt to quantify the groundwater and surface-water interactions within the lower portion of the Pascagoula River Basin with a detailed grain size analysis.

Three questions drive this research. The first research question is related to the surface-water and groundwater interactions pertaining to the management of fresh-water resources along the stream reach. The next two questions pertain to reservoir construction in George County, Mississippi.

1. What portion of streamflow is composed of baseflow within the stream reach before extraction at Pascagoula, Mississippi?
2. What is the hydraulic conductivity of the rock units at the reservoir construction site?
3. How will the hydraulic conductivity influence the reservoir fill time?

Figure 1.2 Map of the study area

The study area is located in southeast Mississippi. This map shows the streams and locations of importance in the study. Data was provided by MARIS and NOAA.

CHAPTER II

SETTING

2.1 Location

The Pascagoula River Basin is located in the southeastern United States and includes 22 counties in Mississippi as well as three counties in Alabama (Newcome, 1967). The reservoirs are proposed in George County, with the lower reservoir extending into Jackson County (Figure 2.1). The stream reach of concern for this study begins at the Okatibbee Dam, located in Lauderdale County and continues to Pascagoula, Mississippi, where the stream terminates at the Gulf of Mexico. The major streams that make up the stream reach include the Okatibbee Creek, which becomes the Chickasawhay River. The Chickasawhay River and Leaf River come together near Merrill, Mississippi to form the Pascagoula River. The Pascagoula River continues to Pascagoula, Mississippi, where it joins with the Escatawpa River. There, the newly joined rivers form a delta as well as marsh areas before entering the Gulf of Mexico.

In George County, the proposed reservoir will fill the shallow valleys where the Big and Little Cedar Creeks currently flow. Big and Little Cedar Creek come together near the town of Lucedale and flow into the Pascagoula River in Jackson County (Figure 2.1).

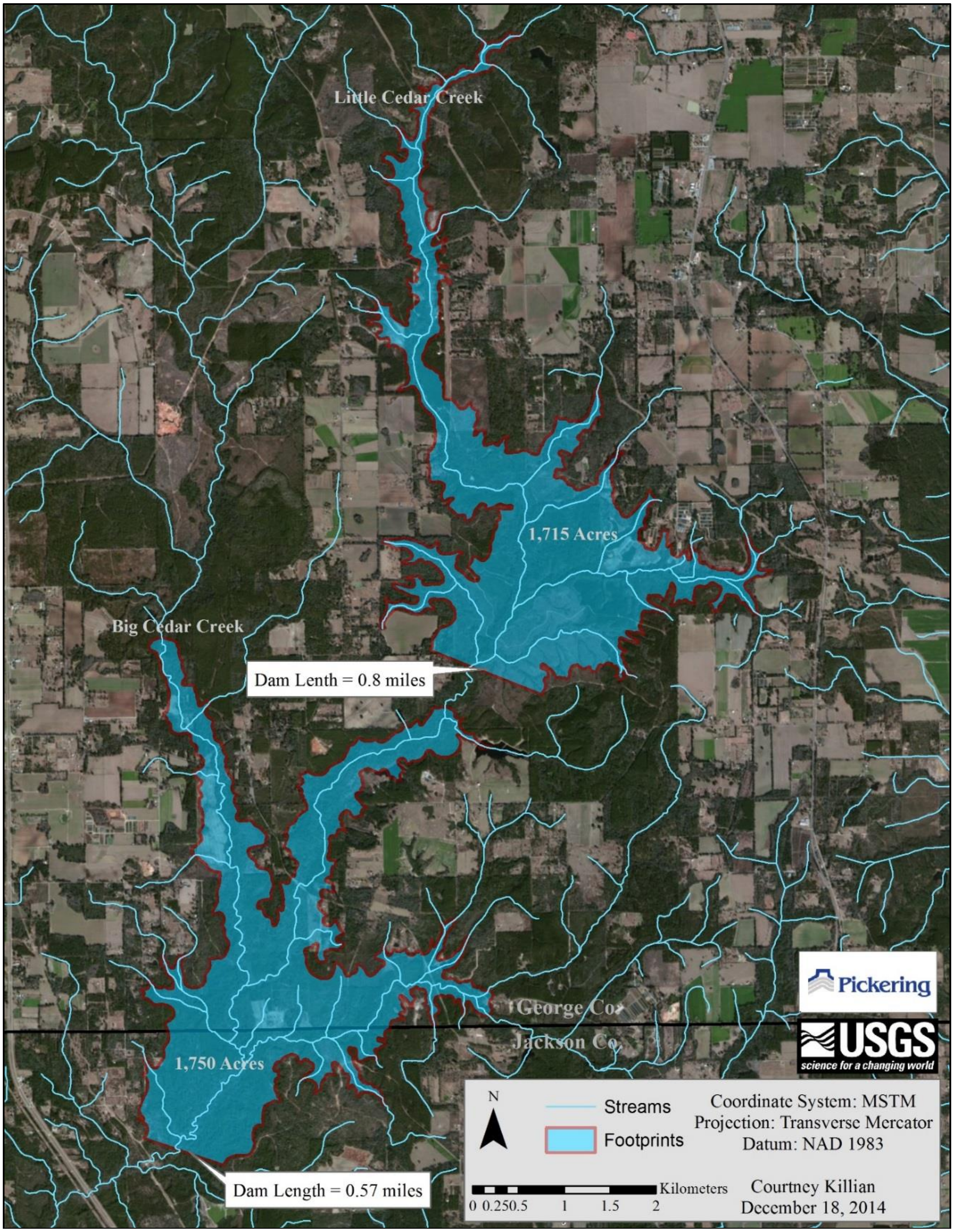


Figure 2.1 Reservoir footprints

The reservoir footprints are located in George and Jackson Counties and were determined using USGS geographic data and by Pickering Firm, Inc.

2.2 Topography & Physiography

The topography within the Pascagoula River Basin changes from rolling hills in the northern part to flood plains and coastal flats in the south (Figure 2.2) (Harvey et al., 1065; Newcome, 1967). Elevation ranges from sea level at the coast to about 213 meters (700 feet) throughout the basin (Newcome, 1967). The Pascagoula River Basin crosses over five physiographic regions: the North and South Central Hills, Jackson Prairie, Pine Belt and the Coastal Zone (Figure 2.2).

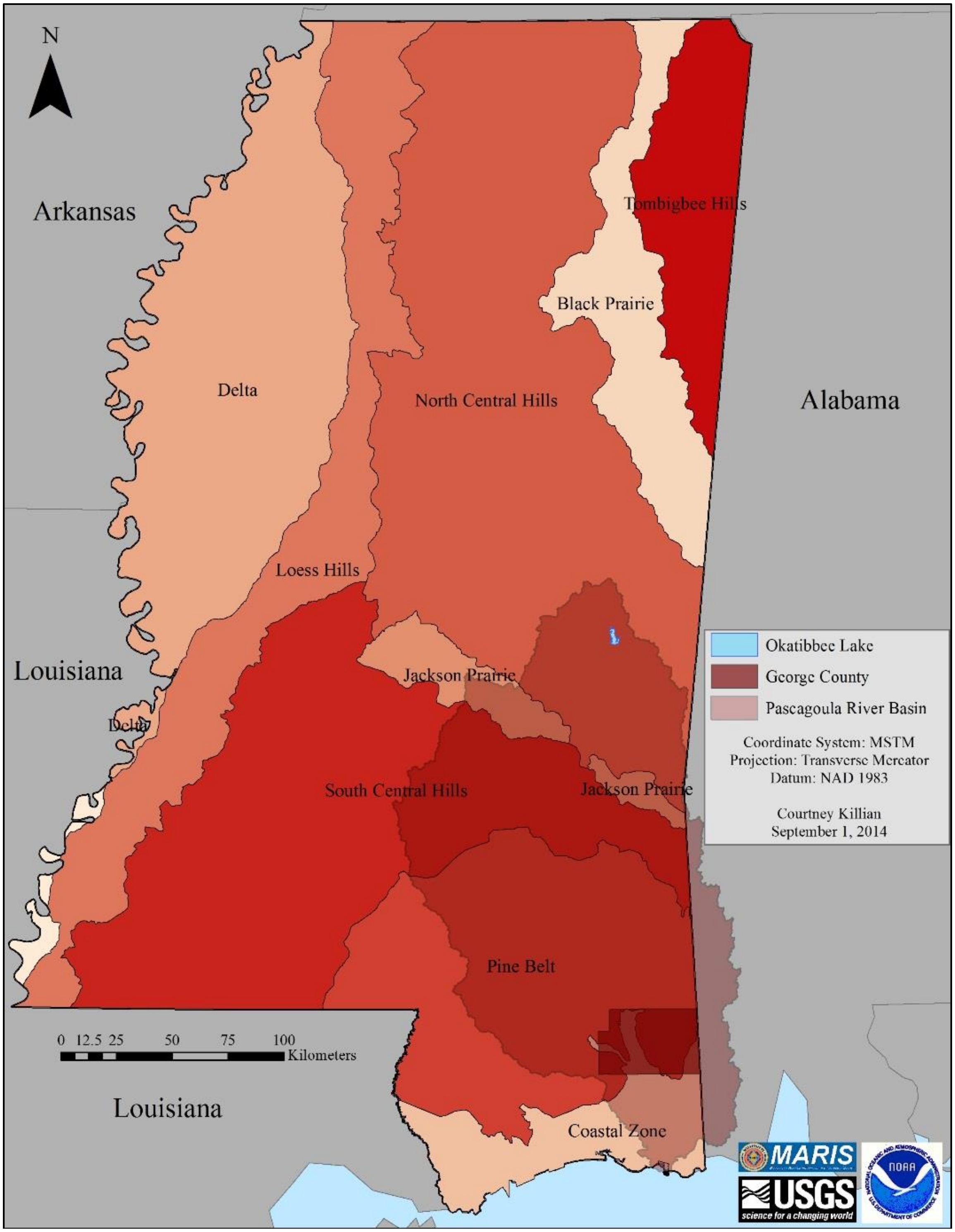


Figure 2.2 Physiographic regions of Mississippi

This map shows the physiographic regions of Mississippi, including the Pascagoula River Basin.

2.3 Geology

The Pascagoula River Basin contains sedimentary rocks ranging in age from Eocene to Quaternary (Newcome, 1967). Most of the stratigraphy is composed of sands and clays with a few limestone units in between. There are four main groups: the Wilcox, Claiborne, Jackson, and Vicksburg (Figure 2.3). The Midway Group is beneath the Wilcox Group in the north, and Miocene rocks are on top of the Vicksburg and Jackson Groups to the south, which include the oldest exposed units (Figure 2.3) (Newcome, 1967). The general dip of the rocks is in the northeast to southwest direction.

The surface geology of the Pascagoula River Basin is composed primarily of units from the Pliocene to more recent alluvial deposits. The Citronelle Formation is one of the older formations, composed of sandstone and gravel as well as some silt or clay, and has a reddish color (Harvey et al., 1965). Terrace deposits can be found on top of the Citronelle Formation and date to the Pleistocene. Alluvial deposits can be found throughout the basin. The clay within the Citronelle Formation is important for the reservoir construction aspect of this study. The clay layer will provide an impermeable layer beneath the reservoirs to help retain water.

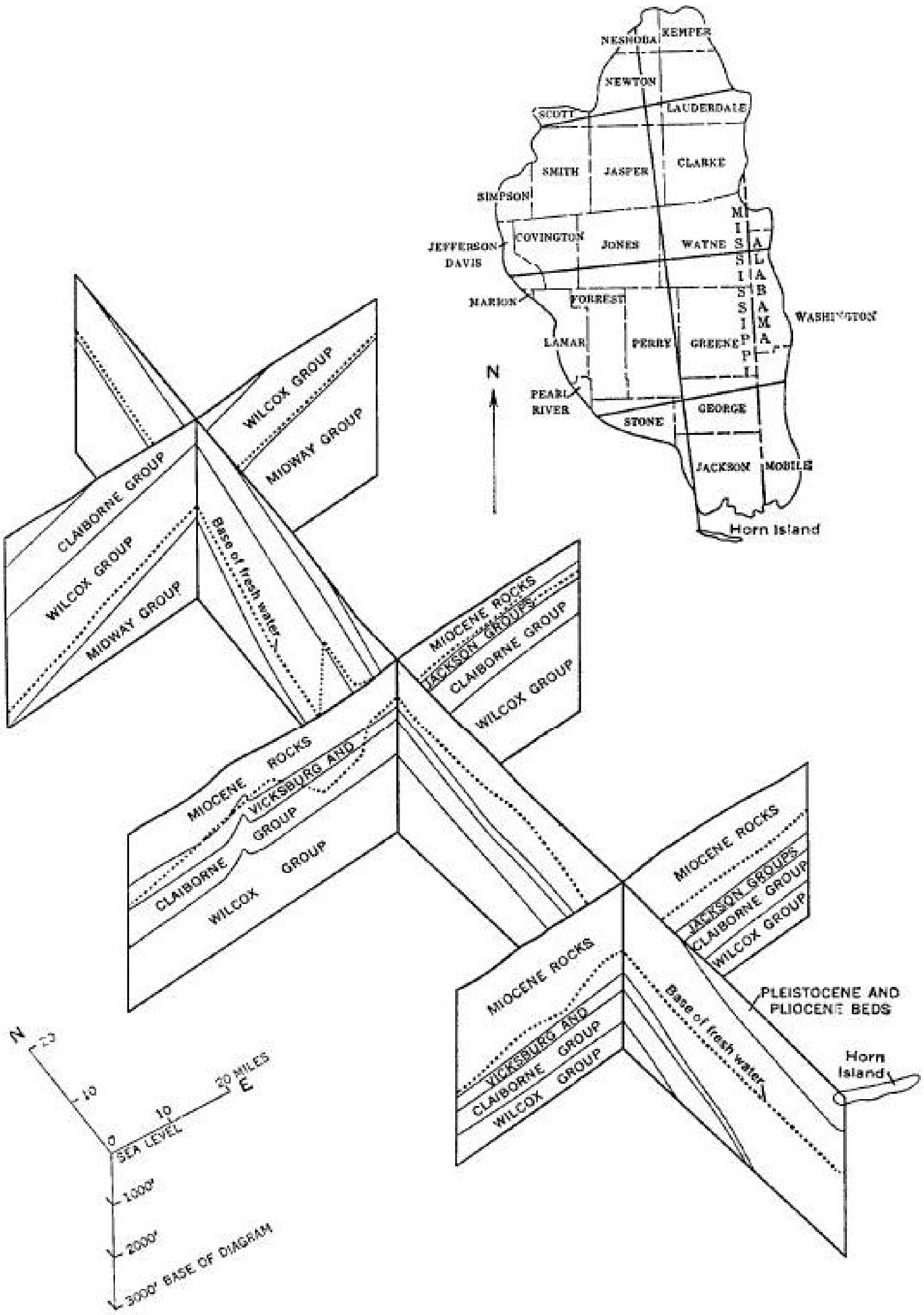


Figure 2.3 Geologic fence diagram

Pascagoula River Basin (Newcome, 1967)

2.4 Hydrology

The Pascagoula River Basin has a drainage area of approximately 24605 square kilometers (9500 square miles) (Harvey et al., 1965; Newcome, 1967). Groundwater discharge to the streams makes up baseflow (Newcome, 1967). The groundwater table is generally within 50 feet of the surface, making it accessible as a water resource (Newcome, 1967). Aquifer thickness is dependent upon the geology and is between 300 to 3500 feet thick depending on the location within the basin (Newcome, 1967). All stratigraphic units are capable of acting as an aquifer with the exception of the Zilpha Clay, Moody's Branch Formation, Yazoo Clay, and the undifferentiated section of the Vicksburg Group (Newcome, 1967). The surface-water stream hydrology of the larger streams, including the Cedar Creek Basin, have been described by Schmitz et al. (2013).

CHAPTER III

LITERATURE REVIEW

A review of previously published literature provides information and insight on topics related to the research project. The main topics include surface-water and groundwater interactions, as well as methods for estimating the availability of water resources and the hydraulic conductivity of unconsolidated sediments.

3.1 Surface-Water & Groundwater Interactions

Archeological findings and written records provided insight into some of the first attempts to manage water resources (Deming, 1954). First attempts include the construction of aqueducts and monitoring channel flow (Deming, 1954).

This research is concerned with the flow and loss of water from the streams that flow from the Okatibbee Reservoir to Pascagoula, Mississippi. Understanding what happens to water in a stream reach will allow for better water resource management, especially in times of low flow or drought. Harvey et al. (1965) provides a water-resource-management study of the Pascagoula River Basin, referencing earlier work conducted in Mississippi regarding surface water and groundwater and their availability as a resource. Newcome (1967) gives background on the availability of groundwater within the basin. Harvey (1965), Newcome (1967), and the United States Army Corps of Engineers (1968) provide background information on the geology of the Pascagoula

River Basin as well as basic water quality and quantity observations. The United States Geological Survey has been monitoring the stream discharge of the basin with continuous record gauging stations from about 1963, but as early as 1939 in some locations (Telis, 1991). Some sites have since been retired. Understanding surface-water and groundwater interactions allows for an educated estimate of the amount of fresh water available for use. The construction of a reservoir at Pascagoula will provide a more consistent and immediate water supply, which will also aid in maintaining stream ecology downstream from the reservoir.

Streams interact in several ways with their surroundings. Winter et al. (1998) and Alley et al. (1999) agree that there are two main types of streams: gaining and losing. A gaining stream receives water from the banks because the groundwater table is higher than the water level of the stream (Winter et al., 1998). If the groundwater table is lower than the stream, the stream will lose water to bank storage (Winter et al., 1998). The literature differentiates between groundwater tables of disconnected streams or surface-water bodies that are just below the surface and streams and surface-water bodies that is deep in the subsurface (Figure 3.1) (Alley et al., 1999; Sophocleous, 2002). Regions with humid climates tend to have gaining streams; arid regions tend to have losing streams (Scanlon et al., 2002). A stream can change seasonally from one type to another, or gain water in one area and lose water in another (Winter et al., 1998; Alley et al., 1999; Smakhtin, 2001; Scanlon et al., 2002). It is important to recognize that the loss or gain of water throughout a stream reach may not be homogenous because a stream could gain or lose water from specific parts of a streambed.

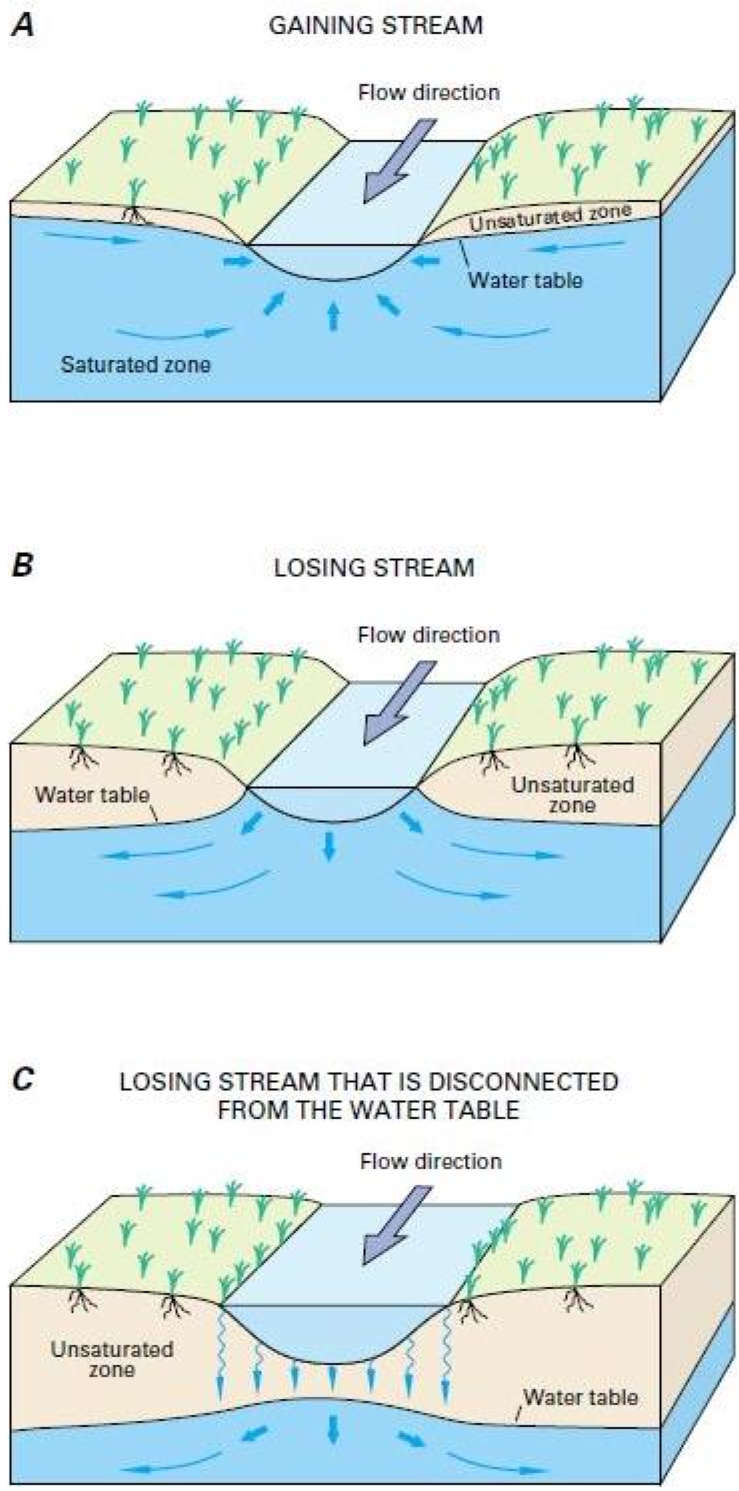


Figure 3.1 Types of groundwater and surface-water interactions

Modified from Winter et al, 1998.

3.2 Watersheds & Groundwater

Watersheds are topographic features, which make defining the movement of surface water directly observable and quantifiable (Winter et al., 2003). Groundwater, on the other hand, is not directly observable and does not have clear boundaries (Winter et al., 2003). Some of the first observations of groundwater suggested that groundwater feeds springs (Meinzer, 1928), which are a surface expression of groundwater (Smakhtin, 2001). The groundwater equivalent of a watershed is a “flow-system divide” (Winter et al., 2003). Surface water and groundwater may not share the same divides and is an important factor to recognize when determining the amount of available water within a basin. The literature used to assume that groundwater and surface water shared the same divides (Hubbert, 1940). Winter et al. (2003) indicates that this is no longer the case. To add another level of complexity to the movement of groundwater, Haitjema (1995) proposed stratification as part of groundwater systems, indicating that groundwater may flow at different velocities at different depths within the groundwater system. Geology has a strong play in this idea.

Surface-water bodies gain water directly from precipitation and runoff. Groundwater replenishment is indirect and happens in two ways, through diffuse and localized recharge (Alley et al., 2002). Diffuse recharge occurs when water from the ground surface percolates down through the earth to the water table (Alley et al., 2002; Rutledge, 2005). Localized recharge refers to the movement of surface water directly to the groundwater table (Alley et al., 2002). According to Winter (2007), groundwater contributes to a high percentage of streams. The mechanics, movement, and recharge behaviors between surface water and groundwater are important to understand when studying surface-water and groundwater interactions. Surface-water and groundwater interactions are important in determining stream discharge and baseflow within the stream reach. The idea of recharge to the groundwater table is also important to consider for the construction of the reservoir.

3.3 History

Groundwater and surface water are now understood to be closely related however, this has not always been the dominant paradime within the discipline of hydrology. Groundwater and surface water were thought to be separate entities that were hardly connected or not connected at all because changes in groundwater were assumed so small that they were not important (Meyer 1928; Verry, 2003). Groundwater and surface water are now described as one entity and regarded by researchers as a dynamic system (Winter et al., 1998; Brodie et al., 2007; Owar et al., 2011). Winter et al. (1998) states the quantity and quality of either surface water or groundwater affects the quantity and quality of the other. An example is pumping groundwater out of an aquifer. The removal of groundwater from the aquifer can lower the groundwater table and affect the amount of groundwater contribution to a stream (Lewelling et al., 1998; Sophocleous, 2002; Brodie et al., 2007; Winter 2007). The connectivity of surface water and groundwater depends on the distance between the two and the lateral flow of water (Sophocleous, 2002; Rassam et al., 2013). The relationship between the different types of water is also important to consider when dealing with contaminants to the water supply system.

3.4 Water-Resource Management

Surface-water and groundwater interactions during low flow or drought periods are important to understand because low flow and drought periods affect the reliability of a water supply (Dingman, 2002). Periods of low flow are also important to water-resource management studies because, during that time, the water in the streams is composed primarily of baseflow (Smakhtin, 2001), which is a reflection of changes in the groundwater table (Collischonn and Fan, 2013). Low flow is an arbitrary term used to define seasonal periods of dry weather (WMO, 1974; Smakhtin, 2001). Drought is a natural event that is a result of an extended period of below average or no precipitation (Cancelliere et al., 1998; Hisdal and Tallaksen, 2000; Smakhtin, 2001). There are several types of drought: meteorological, agricultural, hydrological, and socio-economical (Hisdal and Tallaksen, 2000; Smakhtin, 2001). Smakhtin (2001) points out that drought is a low flow event, but low flow does not necessarily constitute drought.

According to Fetter (2001), understanding how water moves in the subsurface is important in predicting water availability of a hydrologic system in the future. Qualitative and quantitative methods for estimating water availability exist (Chen and Lee, 2003). Some of the methods include the Rorabaugh method (Rorabaugh, 1964; Rutledge, 2005), principal component analysis (Winter et al., 2000; Durães and Rogério, 2013), instantaneous recharge (Mau and Winter, 1997), recession-curve-displacement, base-flow-record estimation method (Chen and Lee, 2003), and recursive digital filtering (Eckhardt, 2005). Each method requires different parameters and has different margins of error. The type of method selected should consider the availability and reliability of the data, as well as space/time relationships (Scanlon et al., 2002). Many of the methods relate to hydrographs, which is a display of water discharge along a stream at a particular point as a function of time (Figure 3.2) (Singh, 1992; Brodie, et al., 2007). When precipitation occurs, the amount of water in a stream temporarily increases and is reflected in the hydrograph. After the rain event, the stream returns to the level it was at prior to the rain event. The water that composes stream flow not contributed from direct precipitation is baseflow, which is a reflection of the groundwater table and groundwater storage.

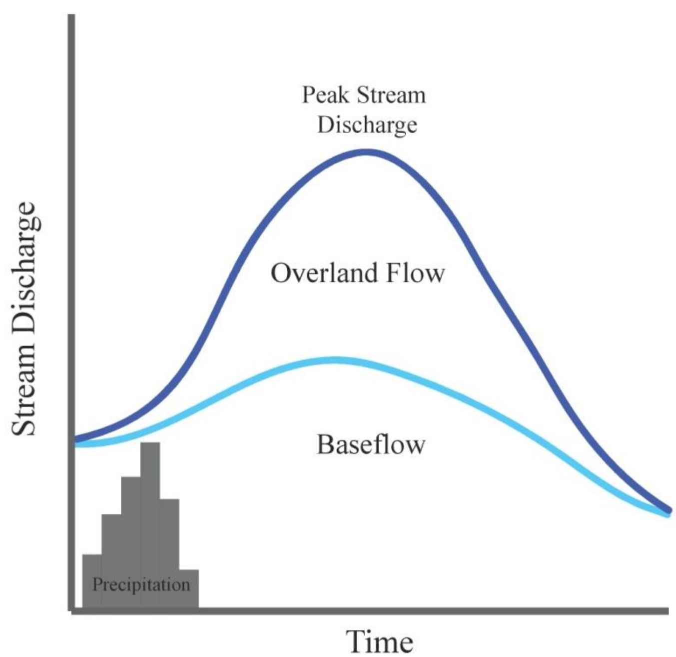


Figure 3.2 Simple hydrograph

Hydrograph separation involves the analysis of stream discharge data to determine which components of streamflow are groundwater and which are surface water. Hydrographs show three different types of flow discharges that make up a stream:

runoff (overland flow), subsurface flow (interflow), and groundwater flow (baseflow) (Meyboom, 1961; Winter, 1981; Singh, 1992; Mau and Winter, 1997; Hannula et al., 2003; Brodie et al., 2007). Hydrographs use stream-discharge data and can show precipitation data with them (Figure 3.2). The United States Geological Survey (USGS) provides precipitation and stream discharge data records that date back to the 1960's for the Pascagoula River Basin. Previous studies in the Pascagoula River Basin state that the baseflow of the streams is sustained from groundwater (Newcome, 1967). Hydrographs aided in the quantifying baseflow in the stream reach for this study.

3.5 Reservoir Construction

The construction of dams and reservoirs changes the distribution of surface water and groundwater. Reservoir construction raises the level of the surface water to increase water availability and storage in an area. A change in the surface-water table will result in a change in the groundwater table.

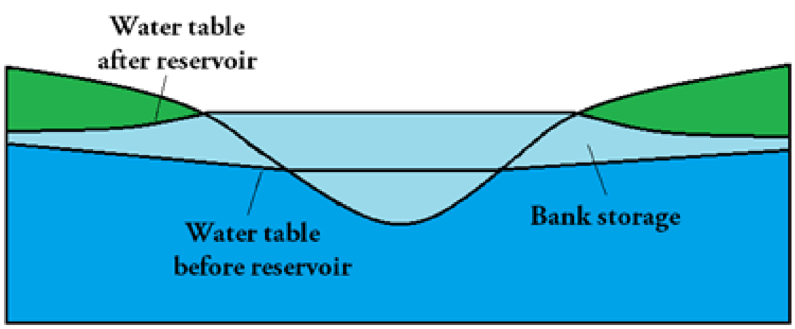


Figure 3.3 Bank storage

This figure represents water loss to bank storage as the water table raises to a new equilibrium.

For a reservoir to be effective, it has to be able to retain water. The ability of the reservoir to retain water is dependent on the geology. Unconsolidated sediment can hold more water than consolidated sediment. Tight rocks such as limestone, clay or crystalline rock can also hold less water because of varying rock permeability and porosity (Singh, 1992). Some rocks, like limestone, are susceptible to dissolution by the water, which can lead to the creation of voids in the subsurface. Previous studies conducted in the Pascagoula River Basin provide a geologic background (Harvey et al., 1965; Newcome, 1967; US ACE, 1968), along with a study conducted to determine where to build the two smaller reservoirs in George County, Mississippi (Personal communication, 2013). The previous studies indicate that the reservoir site contains a clay layer with permeable sand on top (Personal communication, 2013). Weight and Sonderegger (2001) indicate that sedimentary rocks and sediments are the most common and contain water and have a high primary porosity.

The hydraulic conductivity of the geologic units affect the amount of time needed to fill the reservoir after construction (Weight and Sonderegger, 2001). As the reservoir fills, water will move to bank storage until the groundwater table reaches equilibrium in response to the new level of the surface water (Chen and Chen, 2003). Three factors are important to understand about a river before constructing a reservoir: the stochastic nature of the stream, the demand on the water supply, and the reliability of the water supply (McMahon and Mein, 1986). A previous study of the area determined where the reservoir should be located and that it would be more beneficial to construct two small reservoirs rather than one large one (Personal Communication, 2013).

The hydraulic conductivity is obtained from representative rock or soil samples within the subsurface in the study area. Hydraulic conductivity is represented by the coefficient K and is a value that represents how easily water, or another fluid, will pass through material such as rock or unconsolidated sediment (Fetter, 2001). The temperature of groundwater remains relatively constant year-round, with some seasonal influence, and is used to identify springs within streambeds.

CHAPTER IV

STATEMENT OF PROBLEM

4.1 Hypotheses

The research study is centered on two main hypotheses. The first concerns the stream reach from the Okatibbee reservoir to Pascagoula. There, it is thought that water is lost from the streambed to the subsurface during periods of low flow or drought. The second hypothesis is in relation to the reservoir. The hypothesis is that a considerable amount of water will move to bank storage if the water level of the reservoir reaches an elevation high enough to reach the permeable sand layer, which will affect the amount of time needed to fill the reservoir and allow the reservoir to hold more water.

4.2 Objectives

This study has several objectives. The first was to quantify the baseflow in the stream reach to attempt to understand what portion of water within the stream is baseflow using three different methods. The second objective was to compare the results from the three hydrograph-base-flow recession analyses. This was to determine if one method was more effective in quantifying the baseflow than another. The third objective was to determine the hydraulic conductivity of the area where the reservoirs are proposed. This relates to the reservoir fill time and water storage capacity. The last objective was to analyze stream-discharge data collected from continuous monitoring sites put in place by Mississippi State University along the streams of the proposed reservoirs.

CHAPTER V

METHODS

5.1 Surface-Water & Groundwater Interactions

There are several ways to quantify surface-water and groundwater interactions. For this study, three quantitative hydrograph separation methods were used to determine baseflow because they can be generated from existing discharge data. The hydraulic conductivity was found from samples collected around the reservoir construction sites. The rock permeability influences the time it takes for the reservoir to fill after construction, as well as the amount of water that can be held in bank storage. Both the surface-water and groundwater interactions and reservoir construction contribute directly to the amount of fresh water available for extraction and use at Pascagoula, Mississippi.

Hydrograph separation was used to determine the amount of groundwater that contributes to stream flow within the stream reach and is one of the most common methods (Brodie et al., 2007). The stream reach for this project is the length of the stream that begins at the Okatibbee reservoir and terminates at the Gulf of Mexico in Pascagoula, Mississippi (Figure 4). The stream reach includes the Chickasawhay River and the Pascagoula River, taking into account water volumes from major tributaries: the Leaf and Escatawpa Rivers. The construction of the reservoir will also aid in maintaining stream ecology. Water is extracted for municipal, industrial, and recreational use at Pascagoula (Shindala et al., 1973). This study was concerned with separating hydrographs into two main components: quickflow and baseflow. Quickflow and baseflow, together, compose streamflow.

5.1.1 Pascagoula River Basin Stream Reach

Two different hydrograph separation programs were used: the United States Geological Survey's (USGS) program PART and the Web-Based Hydrograph Analysis Tool (WHAT). Three different methods were used: linear interpolation, a one parameter digital filter, and a recursive digital filter. PART uses linear interpolation while WHAT has three options: local minimum, one parameter filter, or a recursive digital filter. All of the hydrograph separation methods generate a Base Flow Indexes (BFI) number, which is a ratio of the baseflow to the total stream flow. The BFI allowed for the three methods to be compared. The three methods were selected because they are three of the more common ways to determine baseflow and there is no absolute correct method yet (Jia et al., 2011).

The data for this analysis was provided by USGS continuous monitoring stations along the stream reach. Some continuous monitoring stations have continuous daily discharge data dating back to 1963, with some as early as 1931. This study looked at approximately the last forty years of discharge data, starting in 1973.Some of the same methods were applied to the continuous monitoring sites put in place by Mississippi State University within the reservoir construction site. The four USGS monitoring sites along the stream reach were chosen based on three criteria: availability of data, completeness of data, and location along the stream reach (Table 5.1) (Figure 5.1).

Table 5.1 Site information for the hydrograph baseflow recession analysis

Site Number	Site Name	Site Location	Drainage Area	
			(mi^2)	(km^2)
02476600	Okatibbee Creek	Arundel, MS	342.0	885.0
02477000	Chickasawhay River	Enterprise, MS	918.0	2377.0
02479000	Pascagoula River	Merrill, MS	6590.0	17068.0
02479310	Pascagoula River	Graham Ferry, MS	8204.0	21248.0

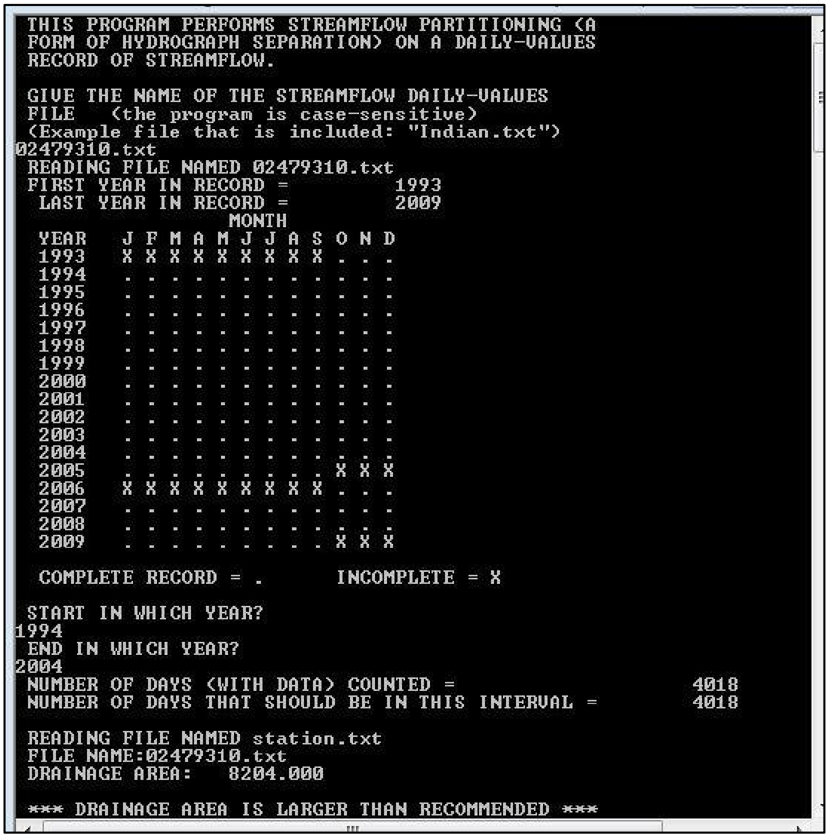
Figure 5.1 USGS stream gauging station locations

The locations of the stream gauging stations used in the study within the Pascagoula River Basin

5.1.1.1 PART

The USGS developed the program PART to separate baseflow from the total streamflow using daily stream discharge data collected at any USGS continuous monitoring sites. The program is DOS -based and works by identifying areas within the data where baseflow and streamflow are equal (Rutledge, 2005; Jia, et al., 2001). The program then uses linear interpolation to determine the baseflow for areas where the two are not equal (Rutledge, 2005).

For the PART program to work properly, at least one full year of daily discharge data is needed. This can be a limitation, because if one day of discharge data is missing, the entire year of record becomes unusable and is omitted in the program. The drainage area must also be known for each station. The program uses English units, so the drainage area must be reported in square miles. The program also reports discharge measurements in cubic feet per second. Figure 5.2 gives an example of the program PART user interface and how the daily discharge data is represented. Months of missing data are obvious to the user.



```
THIS PROGRAM PERFORMS STREAMFLOW PARTITIONING (A
FORM OF HYDROGRAPH SEPARATION) ON A DAILY-VALUES
RECORD OF STREAMFLOW.

GIVE THE NAME OF THE STREAMFLOW DAILY-VALUES
FILE   (the program is case-sensitive)
(Example file that is included: "Indian.txt")
02479310.txt
READING FILE NAMED 02479310.txt
FIRST YEAR IN RECORD =        1993
 LAST YEAR IN RECORD =        2009
                MONTH
 YEAR   J F M A M J J A S O N D
 1993   X X X X X X X X X . . .
 1994   . . . . . . . . . . . .
 1995   . . . . . . . . . . . .
 1996   . . . . . . . . . . . .
 1997   . . . . . . . . . . . .
 1998   . . . . . . . . . . . .
 1999   . . . . . . . . . . . .
 2000   . . . . . . . . . . . .
 2001   . . . . . . . . . . . .
 2002   . . . . . . . . . . . .
 2003   . . . . . . . . . . . .
 2004   . . . . . . . . . . . .
 2005   . . . . . . . . . X X X
 2006   X X X X X X X X X . . .
 2007   . . . . . . . . . . . .
 2008   . . . . . . . . . . . .
 2009   . . . . . . . . . X X X

 COMPLETE RECORD = .      INCOMPLETE = X

START IN WHICH YEAR?
1994
END IN WHICH YEAR?
2004
NUMBER OF DAYS (WITH DATA) COUNTED =                    4018
NUMBER OF DAYS THAT SHOULD BE IN THIS INTERVAL =        4018

READING FILE NAMED station.txt
FILE NAME:02479310.txt
DRAINAGE AREA:   8204.000

*** DRAINAGE AREA IS LARGER THAN RECOMMENDED ***
```

Figure 5.2 Program PART

Screen capture of the user interface of program PART. Dots represent complete months of data and an X represents incomplete data for that month.

5.1.1.2 Digital Filter

The Web-based Hydrograph Analysis Tool (WHAT) was used to determine baseflow for the selected USGS continuous monitoring stations. Within the WHAT program, there are three methods that can be used to separate baseflow from streamflow. There is a local minimum method, the one-parameter digital filter, and the recursive digital filter. The one-parameter filter and the recursive digital filter were chosen for this study. The purpose for using a digital filter is to filter high-frequency data signals in order to find lower-frequency signals, baseflow in this case (Nathan and McMahon, 1990). The WHAT system has been used in previous groundwater and surface-water sustainability studies because of its reliability and consistency with data (Arnold et al., 1995; Lim et al., 2005). The program is also convenient, requiring no software installation like the program PART. WHAT accesses the USGS stream discharge data online; therefore, the drainage area for each station does not need to be known prior to the analysis. Local disk space is also not required to operate the WHAT program.

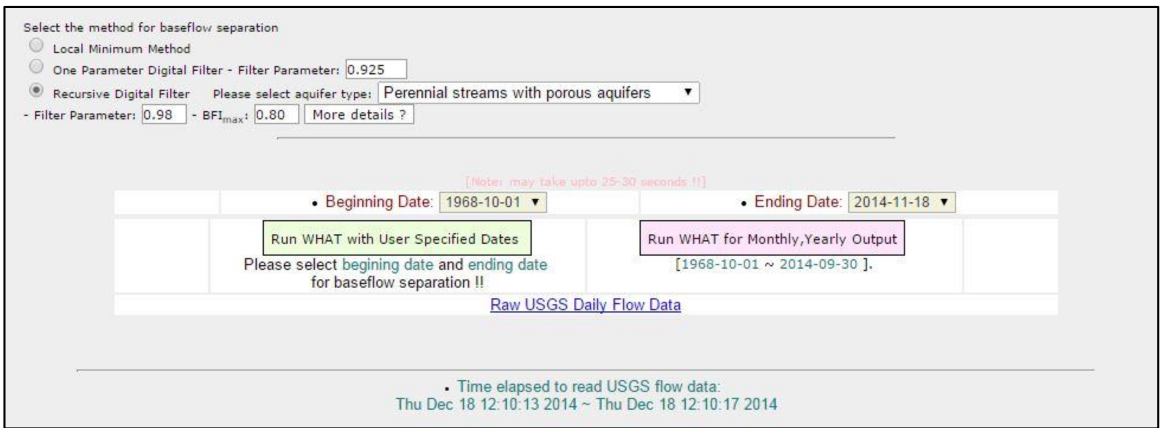


Figure 5.3 WHAT online baseflow-recession analysis resource

Screen capture of the user interface showing default parameters.

5.1.1.2.1 One Parameter Filter

The one parameter digital filter method uses an equation from Lim et al., 2005 to quantitatively separate baseflow from surface flow:

$$q_t = \alpha \cdot q_{t-1} + \frac{(1+\alpha)}{2}(Q_t - Q_{t-1}) \tag{5.1}$$

where q_t is the filtered direct runoff at time step t (m^3/s), q_{t-1} is the direct runoff at time step t-1 (m^3/s), α is the filter parameter, and Q_t is total streamflow at time step t (m^3/s) (Lim et al., 2005). For this study, two different parameters were used: α=0.925 and α=0.98. An α value of 0.925 was used because it is the program default and an α value of

0.98 was used because it was the default value for the recursive digital filter. The default α-values for the filter parameter are based on the type of stream. This allowed for a more direct comparison of the results of each filter output. This equation was based on a single analysis equation developed by Lyne and Hollick, 1979.

5.1.1.2.2 Recursive Filter

The recursive digital filter is another quantitative approach to hydrograph baseflow separation. The recursive digital filter in the WHAT system uses the equation below from Eckhart, 2005:

$$b_k = \frac{(1 - BFI_{max})\alpha \cdot b_{k-1} + (1-\alpha)BFI_{max} \cdot y_k}{1 - \alpha \cdot BFI_{max}} \tag{5.2}$$

where b_k is baseflow at time step k, b_{k-1} is baseflow at time step k-1, y_k equals total streamflow at time step k, BFI_{max} is the baseflow index, and α is the filter parameter. For this study, the default filter parameter of 0.98 was used. A BFI_{max} value of 0.80 is for perennial streams that have porous aquifers. A BFI_{max} value of 0.50 should be used for ephemeral streams with porous aquifers, and a value of 0.25 is recommended for perennial streams that have hard rock or non-porous aquifers (Eckhardt, 2005). The predetermined vales help to minimize human influence on the outcome of the data. The BFI_{max} value used was 0.80 in this study because the stream reach is known to be on top of a porous aquifer. This is also supported by the hydraulic conductivity of the sediments, which is included later in this paper.

5.1.1.3 Base Flow Index (BFI)

The Base Flow Index (BFI), originally proposed by the British Institute of Hydrology, is another way to estimate baseflow and the hydrologic response of a basin. BFI also uses daily stream discharge data (Institute of Hydrology). BFI was originally developed to identify geology and lake storage, but has since been implemented in many baseflow studies. The BFI is a ratio of baseflow to total stream flow. Programs PART and WHAT include BFI values in their output files.

5.1.2 Cedar Creek Basin

Several continuous monitoring sites were put in place by the Mississippi State University Geosciences Department in the area where the reservoirs are to be built to monitor the streams (Figure 5.4, 5.5). Sites CL-3 and CB-5 are of importance in this study. CL-3 stands for Little Cedar Creek and CB-5 stands for Big Cedar Creek. CL-3 and CB-5 continuously record water level, temperature, and rainfall. Periodically, representatives from the Department of Geosciences recorded discharge and stage measurements at the two monitoring sites. The cross-sectional area was recorded at each site. Discharge measurements were recorded with three techniques, depending upon the depth of the water: a StreamPro RDI Acoustic Doppler flow velocity unit by Teledyne Instruments, operated by a Bluetooth enabled HP iPAQ Pocket PC with StreamPro ADCP software installed, a Price AA Current Meter mounted on a wading rod attached to a Rickly Hydrological AquaCount Digitizer, or by recording the average depth, width, and flow velocity were recorded with a stopwatch and engineer’s rule and the Debris Flow Estimation Method was used to calculate the total stream discharge. For streams with a depth greater than two feet, the StreamPro RDI Acoustic Doppler flow velocity unit was used. If the water was less than two feet deep, one of the other methods was used. (Figure 5.4). Hydrographs were generated by graphing discharge against the stage height.

Figure 5.4 Continuous monitoring site and Doppler velocity meter

The continuous monitoring site (left) includes a solar panel, rain gauge, and data recording box, which collects data from the sensor placed in the stream. The Doppler velocity meter (right) collects discharge data using a sonar sensor and calculates discharge from estimates of the cross-sectional area and stream flow velocity.

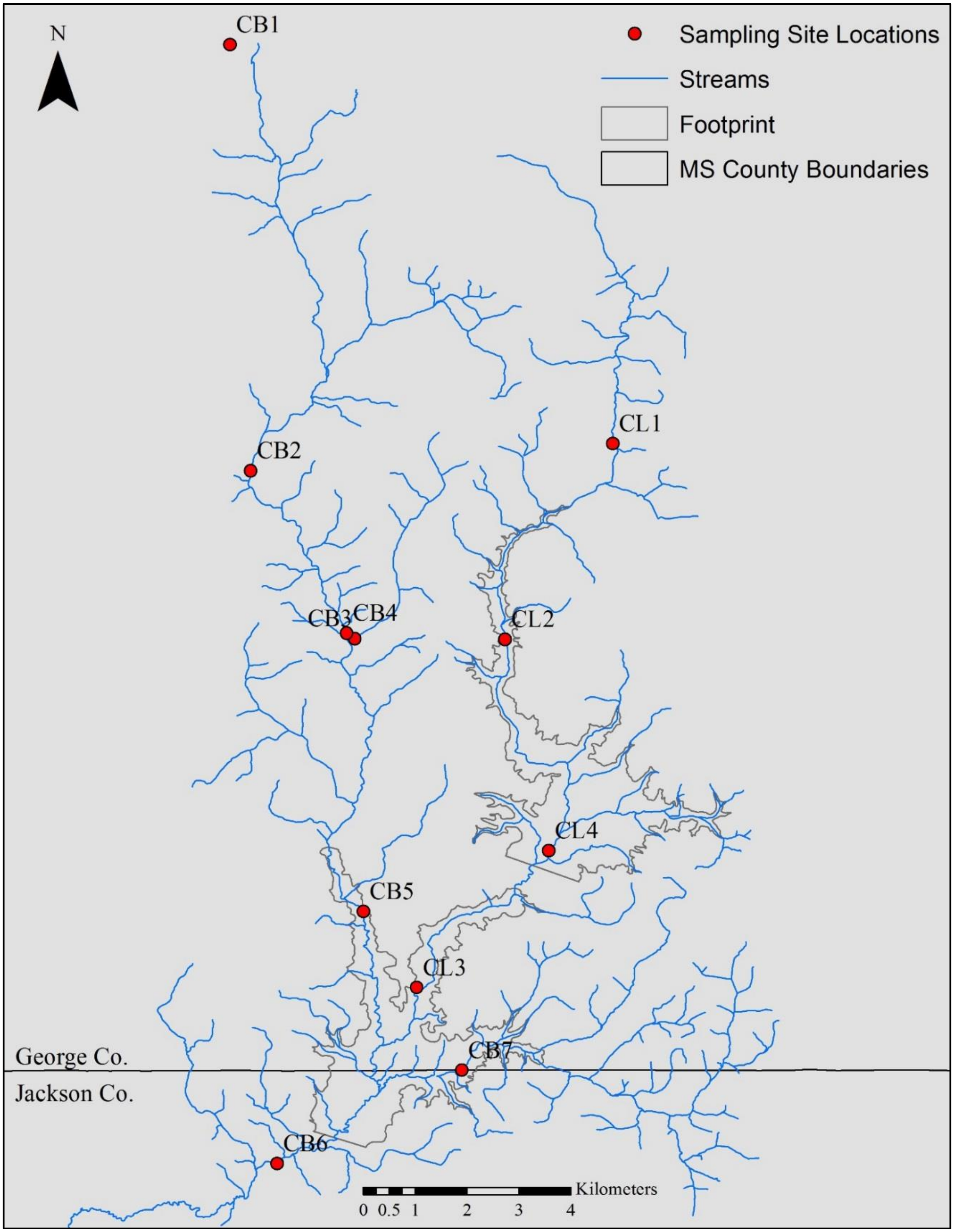


Figure 5.5 Continuous monitoring site locations

The continuous monitoring stations were installed by Mississippi State University. CL-3 and CB-5 are of importance to note for this study.

The baseflow for Big and Little Cedar Creeks was determined by applying the same concepts used by the WHAT online resource in Excel using stage data recorded in feet provided by the continuous recording sites, CL-3 and CB-5. Before the baseflow could be determined, the stream discharge for each site needed to be calculated. Discharge was calculated by graphing several discharge measurements collected by MSU representatives against stage data reported from the continuous monitoring sites for that same day. A line of best fit was interpolated from the graphed data. The equation for the line of best fit for each site allowed for discharge data to be determined from stage data. The equation can be found in figures 5.6 and 5.7.

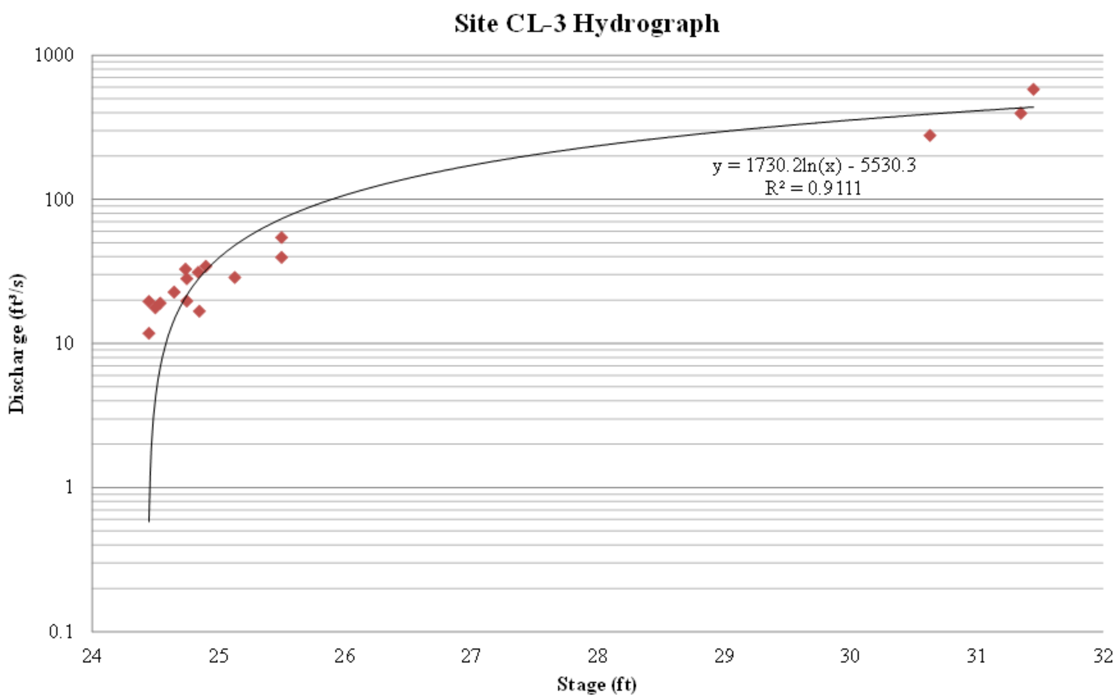


Figure 5.6 CL-3 interpolated discharge hydrograph

The hydrograph shown above was interpolated from field data collected from site CL-3. The data is available in Table 5.2, appended from Foote, 2014.

Table 5.2 Stage and field-collected discharge data for site CL-3.

Date	Stage (s) ft	Discharge ft^3/s
7.26.11	25.5	39.67
8.29.11	24.45	11.77
10.5.11	24.85	16.78
11.15.11	24.75	19.7
1.28.12	25.13	28.8
3.13.12	25.5	54.48
3.23.12	30.63	278.31
5.16.12	24.5	17.7
7.9.12	24.45	19.6
8.2.12	24.54	19.11
8.31.12	31.45	581.32
10.18.12	24.74	32.82
12.18.12	24.84	31.23
4.15.14	31.35	395.469
6.20.14	24.9	34.364
8.12.14	24.75	28.217
11.4.14	24.65	22.711

From Foote, 2014

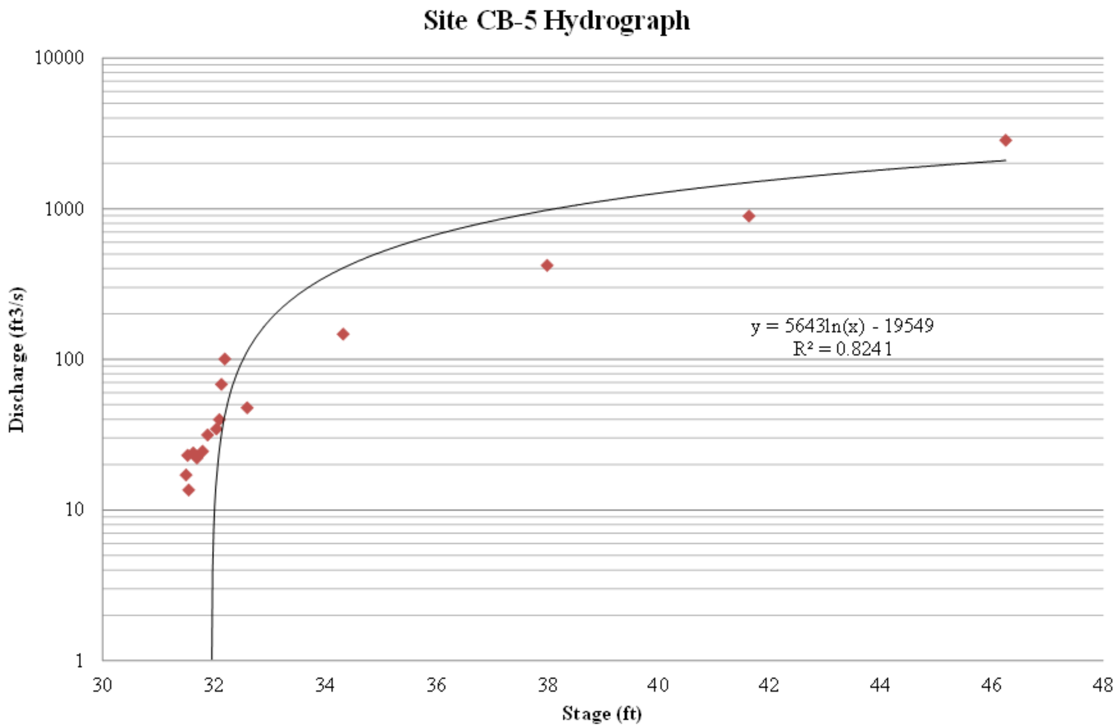


Figure 5.7 CB-5 interpolated discharge hydrograph

The hydrograph shown above was interpolated form field data collected from site CB-5. The data is available in Table 5.3, appended from Foote, 2014.

Table 5.3 Stage and field-collected discharge data for site CB-5

Date	Stage (s) ft	Discharge ft^3/s
7.26.11	32.6	47.73
8.29.11	31.5	17.08
10.5.11	31.7	22.71
11.15.11	31.7	22.16
1.28.12	32.05	34.57
3.13.12	34.33	147.18
3.23.12	41.63	892.87
5.17.12	31.53	23.11
7.9.12	31.55	13.57
8.2.12	31.63	23.88
8.30.12	46.25	2843.84
10.18.12	31.89	31.48
12.18.12	32.1	39.87
4.15.14	38	420.77
6.19.14	32.14	68.26
8.12.14	32.2	100.44
11.4.14	31.8	24.52

From Foote, 2014

5.1.2.1 Digital Filter

To determine baseflow, a newer, simplified algorithm for the one parameter digital filter was used to determine baseflow at CL-3 and CB-5. The newer algorithm was based on equation 5.1 was developed by Chapman and Maxwell (1996):

$$b_t = \frac{\alpha}{(2-\alpha)} * b_{t-1} + \frac{(1-\alpha)}{(2-\alpha)} * (Q_t) \quad (5.3)$$

where b_t is filtered baseflow at time t, b_{t-1} is filtered baseflow at time $t-1$, α is the filter parameter (α=0.925 or α=0.98), Q_t (m^3/s)is total streamflow at time t (Lim et al., 2005). Equation 5.2 was used to determine baseflow using a recursive digital filter. The same parameters, α=0.925 and α=0.98, were applied to the data from CL-3 and CB-5 in Excel.

5.2 Proposed Reservoir Construction

Reservoirs increase the storage capacity of both surface water and groundwater. In George County, Mississippi, two small reservoirs are proposed to increase water storage for industrial and recreational purposes, as well as to maintain stream ecology downstream in times of low flow or drought. The reservoirs are proposed on Big Cedar Creek and Little Cedar Creek. The locations for the reservoirs were determined in a previous study (D. Schmitz et al., Personal Communication, 2013). Before the reservoir can be constructed, two things needed to be identified first: sedimentology and the hydraulic conductivity of the sediments in the basin. To identify the sediments located at the lake footprints and determine a possible fill time for the reservoir a grain size analysis was conducted on 13 sediment samples collected around the perimeter of the proposed reservoirs. The hydraulic conductivity will help to estimate if the reservoir will fill at a slow or fast rate.

5.2.1 Borehole Sampling

An engineering and consulting company, Pickering Firm, Inc., collected the 13 borehole samples with a Geoprobe direct push, hollow stem auger at various locations around the perimeter of the future lake footprints at various depths, usually until probe refusal (Figure 5.8). The sediment was classified by Pickering Firm, Inc. as the boreholes were drilled. The borehole samples were classified based on sediment size (sand, silt, clay) and color and separated into intervals ranging from 0.5 to 4 feet (0.2 to 1.2 meters). After identification, each interval was placed into a Ziploc bag and labeled with the sediment interval for future analysis. PVC pipe was inserted into each borehole that contained water so that water levels could be recorded later. See Appendix B for the detailed sediment descriptions of each borehole sample interval.

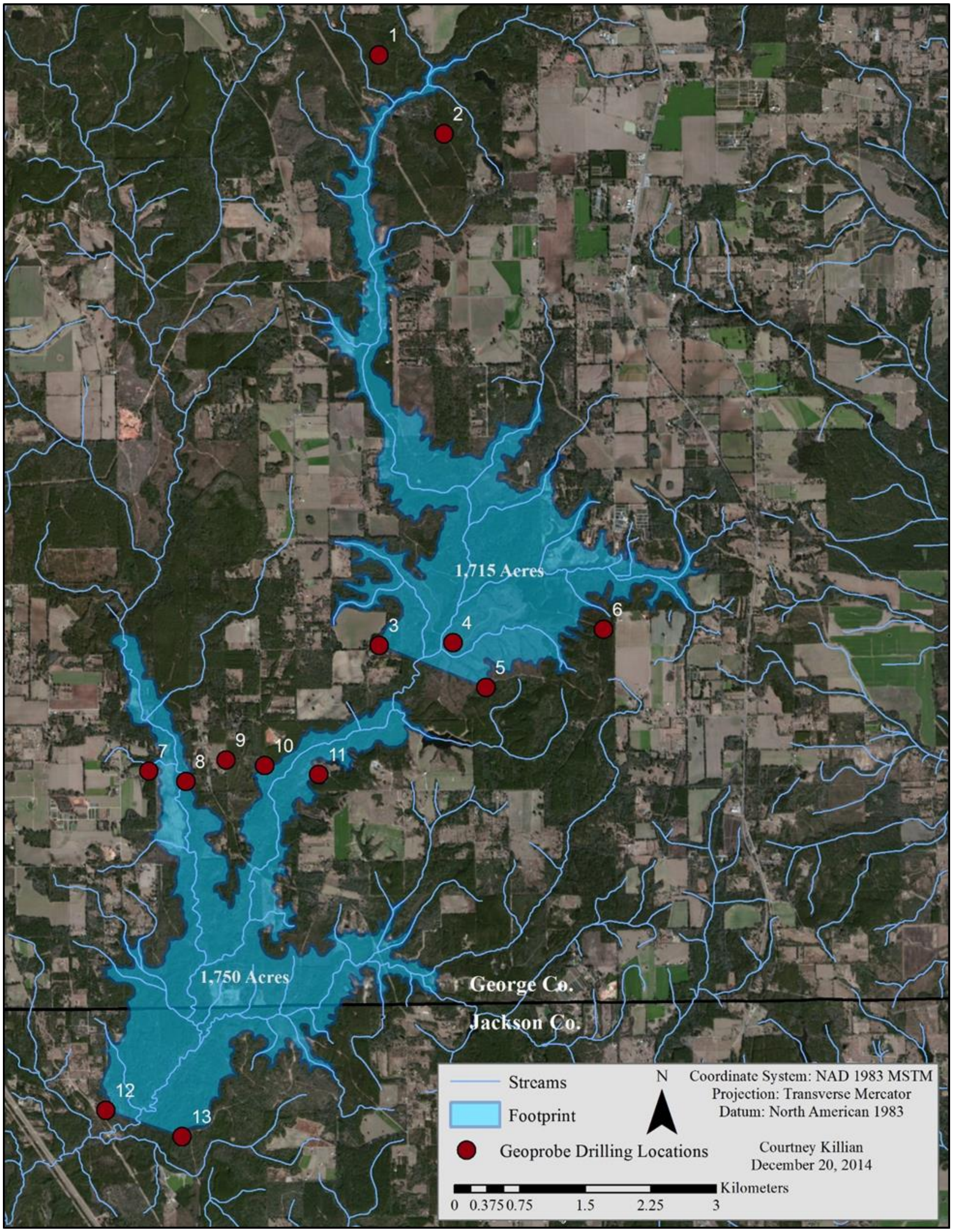


Figure 5.8 Geoprobe drill locations

Drilling locations around the proposed reservoir footprints.

5.2.2 Sieving

Sieving is a process of sorting material by size using wire mesh with known openings. The sieving process uses a series of sieves of different sizes. The size of the sieves used is dependent upon the study. For example, a study concerned with gathering information about large pebbles would not use the same series of sieves as a study concerned with fine sediments such as silt or clay. This study used sieve numbers 10, 18, 35, 60, 120, and 230, along with a catch pan on the bottom (Table 5.2). The sieves were used to obtain grain-size information about the sediments collected by Pickering Firm, Inc.

Table 5.4 Sieve sized used to determine grain size.

<table>
<tr><th rowspan="2">Sieve No.</th><th colspan="2">Sieve Size</th><th rowspan="2">phi</th><th rowspan="2">Description</th><th rowspan="2">Type</th></tr>
<tr><th>Millimeters</th><th>Microns</th></tr>
<tr><td>10</td><td>2</td><td>2000</td><td>-1</td><td rowspan="7">Very coarse sand
Coarse sand
Medium sand
Fine sand
Very fine sand
Very coarse silt</td><td>Gravel</td></tr>
<tr><td>18</td><td>1</td><td>1000</td><td>0</td><td rowspan="5">Sand</td></tr>
<tr><td>35</td><td>0.500</td><td>500</td><td>1</td></tr>
<tr><td>60</td><td>0.250</td><td>250</td><td>2</td></tr>
<tr><td>120</td><td>0.125</td><td>125</td><td>3</td></tr>
<tr><td>230</td><td>0.063</td><td>63</td><td>4</td></tr>
<tr><td>Pan</td><td><0.063</td><td><63</td><td>NA</td><td>Silt</td></tr>
</table>

Descriptive terms based on Udden (1914), Wentworth (1922), Friedman and Sanders (1978) found in Blott and Pye (2001).

5.2.3 Grain Size Analysis

The sieves were used to obtain information about the grain size distribution of the 13 borehole samples collected from around the reservoir footprints. The grain size analysis was conducted at Mississippi State University using the series of six sieves previously discussed.

The grain size analysis was conducted following the outline found in Driscoll (1986). Each sample was dried for at least five minutes using a Panasonic 1.7 cubic foot (0.05 cubic meter), 1100-watt microwave. After each sample was dried, it was examined to ensure that all of the grains were separated and not clumped together. Then, the sample was re-microwaved to ensure the sample was completely dry. If the sample still showed signs of moisture, the sample was microwaved again. The dry sample was weighed using a Denver Instruments SI-234 scale, accurate to four decimal places, to obtain an initial weight. All of the samples were weighed in plastic weighing boats and the weight of the boats was removed using the tare function on the scale. Each sample was then sieved by hand for at least five minutes or more until no more sediment would move through the sieves (Driscoll, 1986). When complete, the contents of each sieve was transferred to a paper plate marked with the borehole number, depth interval, and sieve size and weighed with the scale using a plastic boat. All data was recorded in a field notebook and then transferred to Excel for analysis. This allowed a grain size distribution to be determined by weight percentages. Error was recorded as well. When the weight was determined for each sieve sample, the sample was returned to its labeled Ziploc bag for storage. This study focused on the grain size distribution for the sand layers, therefore no samples, clay and silt sized or smaller, were sieved.

Figure 5.9 Sieve stack and Denver Instruments SI-234 scale

The sieve stack (left) was used to separate the samples by grain size. The scale (right) was used to weigh each sample to obtain a weight percent for each sieve.

The hydraulic conductivity for each sample and sample interval was calculated using the following equation from Singh, 1992, based on the Hazen method:

$$k = C(d_{10})^2 \tag{5.4}$$

where k is the hydraulic conductivity (cm/s), C is a unitless constant that depends on the rock type, and d_{10} is the mean grain diameter (cm), or effective grain size, which is between 0.1 and 3.0 mm (Fetter, 2001). The rock type present at the locations of the reservoirs will determine the unitless constant *C*, which can be determined from the following table from Fetter, 2001 (Table 5.5).

Table 5.5 Hydraulic conductivity coefficient *C*

Very fine sand, poorly sorted	40-80
Fine sand with appreciable fines	40-80
Medium sand, well sorted	80-120
Coarse sand, poorly sorted	80-120
Coarse sand, well sorted, clean	120-150

CHAPTER VI

RESULTS

6.1 Surface-Water & Groundwater Interactions

6.1.1 Pascagoula River Basin Stream Reach

The baseflow recession analysis for this study was done in response to the question of what portion of the streamflow in the stream reach from Okatibbee Lake to Pascagoula is composed of baseflow. This is important to understand because it gives an estimate of water resources that are stored as groundwater. The baseflow hydrographs for all four stations for the period of interest are in Appendix A. The hydrographs show that baseflow varies depending upon the season. Baseflow is typically higher from about December to July.

6.1.1.1 PART

The USGS program PART provided insight into the groundwater and surface-water interactions of the stream reach. Four USGS stations were used. The location of the stations took contributions of major tributaries into account. The program was able to analyze data from January 1973 to December 2013 for stations 02476600, 02477000, and 02479000. Station 02479310 was not installed until October 1, 1993 and had continuous daily discharge data available up until the end of 2004, and again from 2007 to 2008. The station was decommissioned September 30, 2009. Station 02479310 was included in the study because it was the closest station to the Gulf of Mexico that had a considerable amount of daily stream discharge data. The PART analysis results summary for the stream reach is provided the in Table 6.1

Table 6.1 PART baseflow recession analysis summary

USGS Station		**02476600**	**02477000**	**02479000**	**02479310**	
Drainage Area	(mi^2) (km^2)	342.00 885.00	918.00 2377.00	6590.00 17068.00	8204.00 21248.00	
Time Period		1973-2013	1973-2013	1973-2013	1994-2004	2007-2008
Mean Stream Flow	(cfs) (cms) (in/yr) (m/yr)	516.16 14.62 20.50 0.52	1366.73 38.70 20.22 0.51	10469.82 296.47 21.58 0.55	12027.55 340.58 19.91 0.51	7055.64 199.79 11.68 5.07
Mean Baseflow	(cfs) (cms) (in/yr) (m/yr)	333.44 9.44 13.24 0.34	726.32 20.57 10.75 0.27	5845.12 165.60 12.05 0.31	7359.45 208.40 12.19 0.31	4239.90 120.06 7.02 0.18
Base Flow Index		0.65	0.53	0.56	0.61	0.60

Summary of the four USGS gauging stations analyzed in this study

The program PART showed that the streamflow and baseflow increase from upstream at Okatibbee Lake down to Pascagoula. This is also supported as the drainage area increases from upstream to downstream, taking more and more of the basin into account. At Pascagoula, almost all of the 9200 square miles of the Pascagoula River Basin are accounted for. Graphically, the results of PART give one of the lower estimation of baseflow, however, the slopes of the lines show a more drastic change in response to rainfall. This suggests that the aquifer responds rapidly to changes in the water table. A lower estimation of baseflow would be better to use in order to properly manage water resources. A lower estimation of water resources will result in a lower chance of running out of sufficient water resources.

6.1.1.2 Digital Filter

6.1.1.2.1 One Parameter Filter

The one parameter filter with filter parameter α=0.925, the default parameter for WHAT, on average estimated the highest baseflow for the stream reach. The baseflow estimation using this method was between 61 and 70 percent baseflow for the stream reach. This may not be the best method for estimating baseflow because it may overestimate the quantity of water actually available for use.

The one parameter filter with filter parameter α=0.98 gave an average estimation of baseflow from 47 to 66 percent. This method gave one of the lower estimations for baseflow. Graphically compared to the results from PART, the results from this analysis appear to be more realistic. The lines have a more consistent slope and have fewer sharp jumps in baseflow. This analysis, using a filter parameter of α=0.98, suggests that the aquifer responds to changes in the water table, but not as drastically as the results of program PART suggest. This may be the more preferable method to use. The hydrographs for the forty-year period for each station showing each baseflow-recession parameter are in Appendix A.

6.1.1.2.2 Recursive Filter

The recursive digital filter, similar program PART, gave a baseflow estimation that was not the highest. The WHAT recursive digital filter, using the default parameter

α=0.98, gave a baseflow estimation of between 51 and 66 percent. The recursive digital filter gave results similar to the WHAT one parameter filter with filter parameter α=0.925. The recursive digital filter results appear similar to that of the one parameter filter with filter parameter α=0.925, but do not give as high of an estimation of baseflow.

For station 02479000, the recursive digital filter did not appear to accurately estimate the baseflow. The line jumps drastically from an estimated value to zero and back throughout the dataset, creating a jagged line that provides a low baseflow estimation. The same dataset was used in both programs, but with different filter parameters. Since the recursive digital filter provided inaccurate results for station 02479000, the recursive digital filter is not the best method for estimating baseflow in this study. The method may be useful in other studies, however.

6.1.1.3 Base Flow Index (BFI)

The four baseflow analyses, conducted with programs PART and WHAT, reported a Base Flow Index (BFI) value for each station. The BFI is a ratio of the baseflow to the total streamflow. The results of each analysis are in Table 6.2. The results of the BFI indicate that the stream reach may have a baseflow component of between approximately 50 and 70 percent baseflow, decreasing slightly and then increasing again before the stream enters the Gulf of Mexico (Figure 6.1).

Table 6.2 Base Flow Index results of the PART and WHAT hydrograph baseflow-recession analysis

USGS Stations	02476600	02477000	02479000	02479310	
Time Period	1973-2013	1973-2013	1973-2013	1994-2004	2007-2008
PART	0.65	0.53	0.56	0.61	0.60
WHAT - One Parameter 0.925	0.69	0.61	0.67	0.70	
WHAT - One Parameter 0.98	0.52	0.47	0.64	0.66	
WHAT - Recursive Filter 0.98	0.65	0.60	0.51	0.66	

Note: no data for PART analysis between years 2004 and 2007 for gauging station 02479310.

The WHAT one parameter filter with α=0.925 indicated the highest percentage for baseflow for the stream reach. Program PART and the WHAT recursive digital filter with α=0.98 reported similar baseflow estimations. The WHAT one parameter filter with α=0.98 showed that the baseflow increases before it enters the Gulf of Mexico. All four analyses showed a decrease at station 02477000 (Figure – BFI graph). Overall, baseflow decreases at the stream flows from Okatibbee Lake and increases again before it reaches Pascagoula. This significant find may suggest that, during periods of low flow, some water could be lost to bank storage.

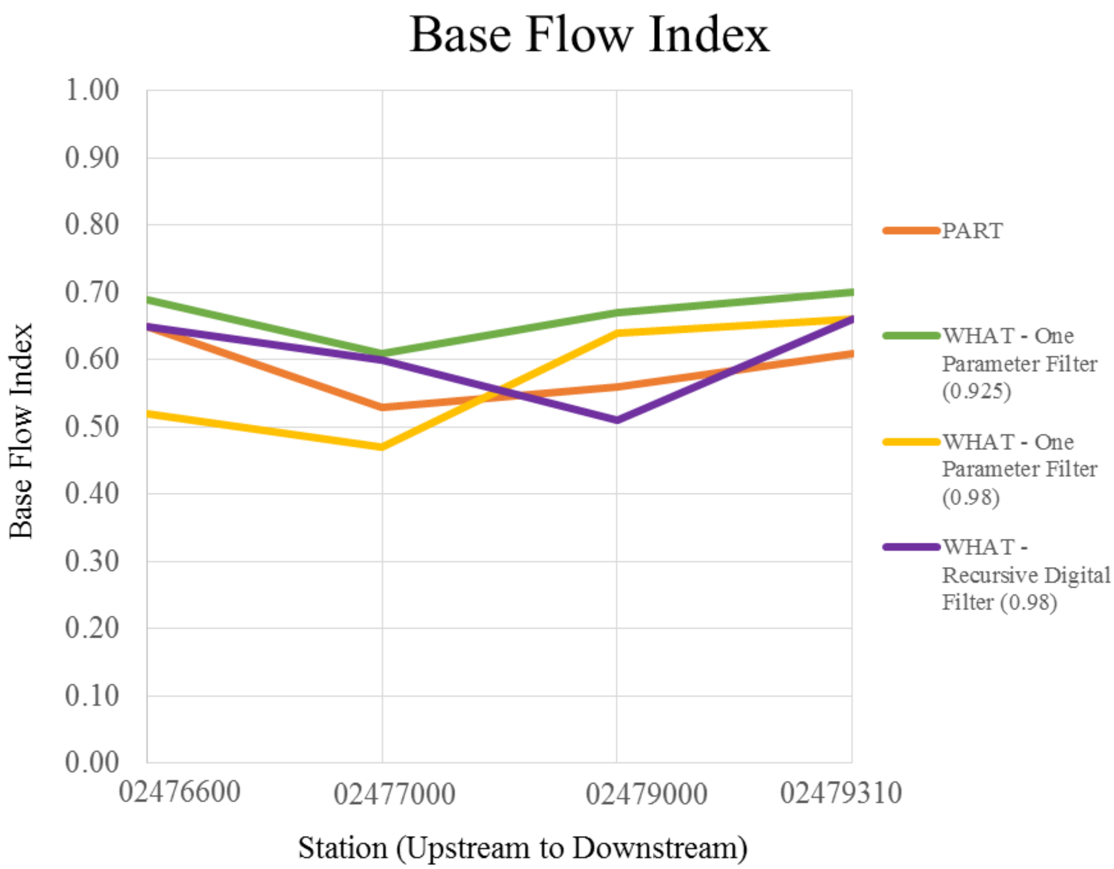


Figure 6.1 Base Flow Index graph

The graph shows all parameters from both methods (PART and WHAT)

6.1.2 Cedar Creek Basin – Reservoir Construction Site

Representatives from the Department of Geosciences at Mississippi State University recorded discharge measurements at CL-3 and CB-5 over the course of a few years. The discharge measurements provided enough data to generate hydrographs for the two monitoring stations located near the bases of the proposed reservoirs (Figure 5.4).

Site CL-3 had an average discharge of 8.69 feet per second from May to December of 2014. The avarage baseflow according to the one parameter digital filter using filter parameter α=0.925 was 4.35 feet per second. This suggests that the baseflow component estimate is about 50 percent of total streamflow. The one parameter digital filter using filter parameter α=0.98 was also 4.35 feet per second, or 50 percent of total streamflow. The recursive digital filter using filter parameter α=0.98 and BFI_{max}=0.80 reported an average baseflow value of 6.95 feet per second, which is about 80 percent of total steamflow. The results of baseflow for CL-3 give a range of between 50 and 80 percent, however, one year's worth of data was used in comparison to approximatley 40 years worth for the baseflow estimatin in the main stream reach.

Site CB-5 had an average discharge of 9.42 feet per second from December, 2011 to December, 2014. The avarage baseflow according to the one parameter digital filter using filter parameter α=0.925 was 4.71 feet per second, estimating the baseflow component of the stream to be about 50 percent. The one parameter digital filter using filter parameter α=0.98 was also 4.71 feet per second, or 50 percent of total streamflow. The recursive digital filter using filter parameter α=0.98 and BFI_{max}=0.80 reported an average baseflow value of 7.53 feet per second, which is about 80 percent of total steamflow. The three parameters give a baseflow estimation for the stream at site CB-5 to be between 50 and 80 percent of total streamflow for about three years worth of data.

6.2 Proposed Reservoir Construction

6.2.1 Borehole Sampling

Borehole sampling allowed for an analysis to be done to help answer the research questions regarding porosity and permeability of the sediment at the reservoir construction sites as well as give insight to if the reservoir will fill fast or slow after its construction. The 13 boreholes drilled by Pickering Firm, Inc. revealed that the reservoirs are proposed on top of unconsolidated sediment that ranges from sand to clay.

Boreholes 1 to 6 were drilled around the upper reservoir footprint. Borehole 1 (GC-1) was drilled in the northern area of the upper reservoir footprint (Figure 5.5). Borehole 1 was drilled to geoprobe refusal at a depth of 26 feet (8 meters). Borehole 2 was drilled in the northern area of the upper reservoir footprint, a few kilometers south east of borehole 1. Borehole 2 (GC-2) was drilled to a depth of 56 feet. Borehole 3 (GC-3) was drilled in the south-west corner of the upper footprint at the left side of where the upper dam is proposed. Borehole 3 was drilled to a depth of 32 feet. Borehole 4 (GC-4) was drilled inside the upper reservoir footprint, north of where the dam will be located and east of borehole 3.Borehole 4 was drilled until refusal, reaching a depth of 32 feet. Borehole 5(GC-5) was drilled where the right side of the dam will be located, southeast of borehole 4 to a depth of 8 feet (2.4 meters). Borehole 6 (GC-6) was drilled east of the main body of the upper footprint to a depth of 24 feet until geoprobe refusal (Figure 5.5).

Boreholes 7 through 13 were drilled around the perimeter of the lower reservoir footprint. Borehole 7 (GC-7) was drilled along the left perimeter of the left finger extending from the lower reservoir footprint, southeast of the upper footprint. Borehole 7 was drilled to a depth of 56 feet and well casing was installed. Borehole 8 (GC-8) was drilled east of borehole 7, on the right perimeter of the left finger of the lower reservoir. Well casing was installed in borehole 8 with a well screen at 20 feet. Borehole 9 (GC-9) was drilled northeast of borehole 8, between both fingers that extend north from the lower reservoir footprint. Borehole 9 was the deepest hole, with a depth of 68 feet. A well was pushed and set to a depth of 79 feet. Borehole 10 (GC-10) was drilled on the left perimeter of the right finger that extends north from the lower footprint to a depth of 16 feet. Heaving sand was encountered at 12 feet and a well was pushed to 37 feet with a screen at 20 feet. Borehole 11 (GC-11) was drilled east of borehole 10 along the perimeter of the right finger of the lower footprint. Well casing was pushed into borehole 11 and set to a depth of 46 feet with a well screen at 20 feet. Heaving, wet sand was encountered in borehole 11 at 40 feet. Borehole 12 (GC-12) was drilled at the location of the left side of the dam of the lower footprint, to a depth of 52 feet. Borehole 13 (GC-13) was drilled at the location of the right side of the dam that is proposed to create the lower reservoir footprint. Borehole 13 was drilled to a depth of 46 feet (Figure 6.2).

Water was found in wells 7, 8, 9, 10, and 11. Piezometers were installed in these five wells. Some of the other borehole samples were wet when they were extracted, but piezometers were not installed. Initial well water levels were recorded after the wells were drilled, as well as a few other dates, recorded in Table 2. The detailed borehole logs can be found in Appendix B. Cross section A to A' runs through boreholes 7, 8, 9, 10, and 11. Cross section B to B' runs through boreholes 1, 8, and 12 (Figure 6.3). The cross sections are vertically exaggerated to show change in topography.

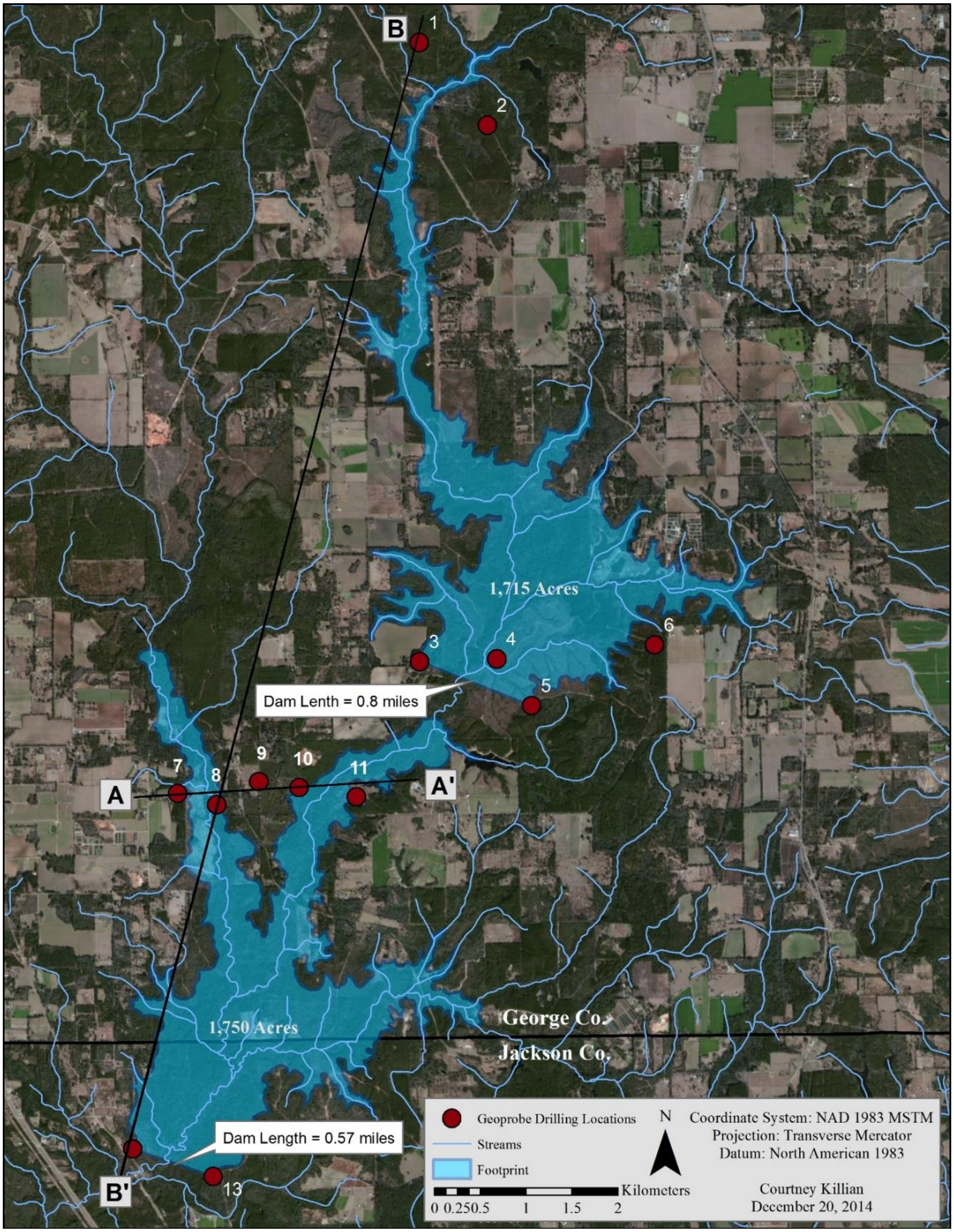


Figure 6.2 Cross sections A-A' and B-B'

Table 6.3 George County Monitoring Wells, depth to water

Site			**7**	**8**	**9**	**10**	**11**
Location	WGS84	Latitude	30.759406 N	30.758288 N	30.760479 N	30.759849 N	30.75889 N
		Longitude	88.577756 W	88.573338 W	88.568501 W	88.563910 W	88.55742W
Casing Height (above ground) (ft)			1.10	2.15	0.60	2.90	4.00
Total Well Depth (ft)			56.50	29.70	80.30	39.70	49.40
Date	Depth to Water (ft)						
7/11/2014	top of casing		36.95	7.72	63.25	4.42	24.65
	ground		35.85	5.57	62.65	1.52	20.65
10/6/2014	top of casing		39.53	8.51	65.80	5.09	25.08
	ground		38.43	6.36	65.20	2.19	21.08
11/3-4/2014	top of casing		40.40	8.90	66.60	5.70	25.50
	ground		39.30	6.75	66.00	2.80	21.50

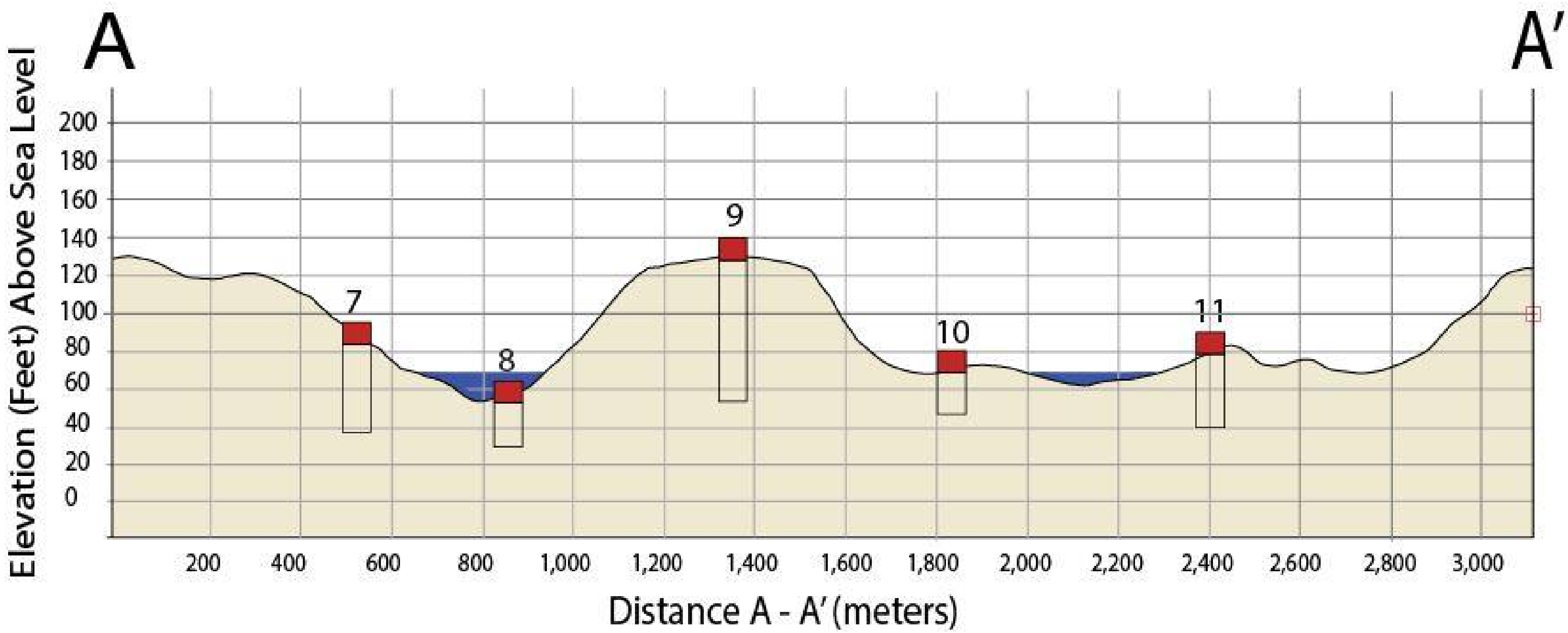


Figure 6.3 Cross section A to A’ construction

Vertically exaggerated, showing boreholes 7 to 11 and water level (blue) after reservoir construction.

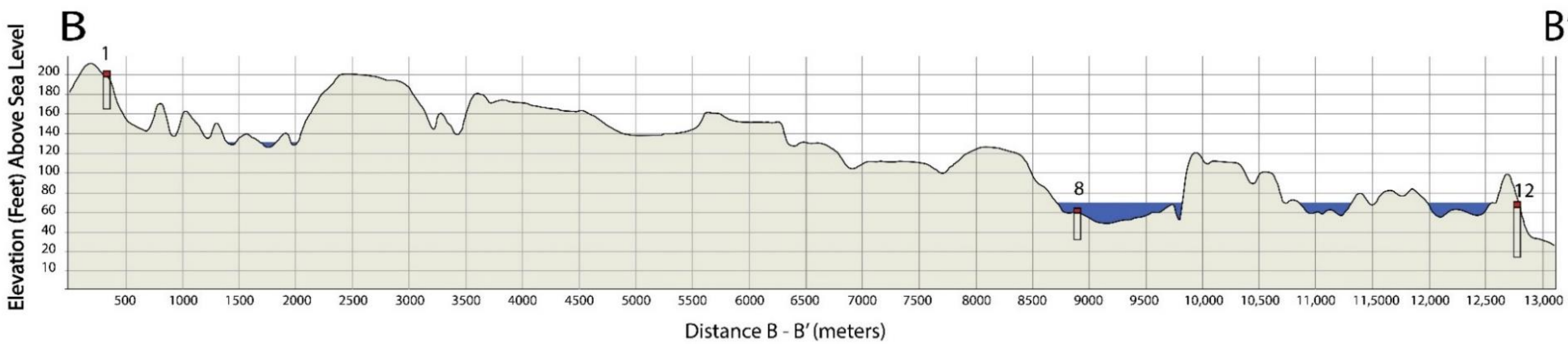


Figure 6.4 Cross section B to B’

Vertically exaggerated, showing boreholes 1, 8, and 12 with water level (blue) after reservoir construction.

6.2.2 Grain Size Analysis

The grain size analysis was conducted at Mississippi State University using the 13 borehole samples collected by Pickering Firm, Inc. to determine the hydraulic conductivity of each borehole drilled around the perimeter of the future reservoir footprints. The grain size analysis was conducted to answer questions concerning the construction of the reservoirs in George County, Mississippi. The questions that prompted the analysis were concerned with the porosity and permeability of the sediment at the reservoir construction sites as well as how the porosity and permeability would affect the amount of time needed to fill the reservoirs after their construction. For detailed information about each the grain size analysis for each borehole, including the cumulative grain size curves for each sample, see Appendix C.

The grain size analysis revealed that the sediment in the area where the reservoirs are proposed is composed primarily of sand, as well as some silt and clay. The sands were medium in size and well sorted. From this, the *C* coefficient value based on the table from Fetter, 2001 has a value range of 80-120 (Table 5.3). The hydraulic conductivity of the silt and clay layers was not of concern for this study.

Ten samples were extracted from borehole 1 (GC-1). From 0-2 feet, majority of the sample was contained in sieve number 60 with a grain size of 0.025mm. From 2-4 feet and 4-5 feet, the majority of the samples were contained in sieves 60 and 120 with grain sizes between 0.025mm and 0.0125mm. The borehole contained clay from 5-26 feet, and therefore could not be sieved. The average error for borehole 1 was a loss of less than 1 percent of the sample. The overall hydraulic conductivity for borehole 1 is between 257 and 385 m/day and is as low as 173 m/day and as high as 583 m/day.

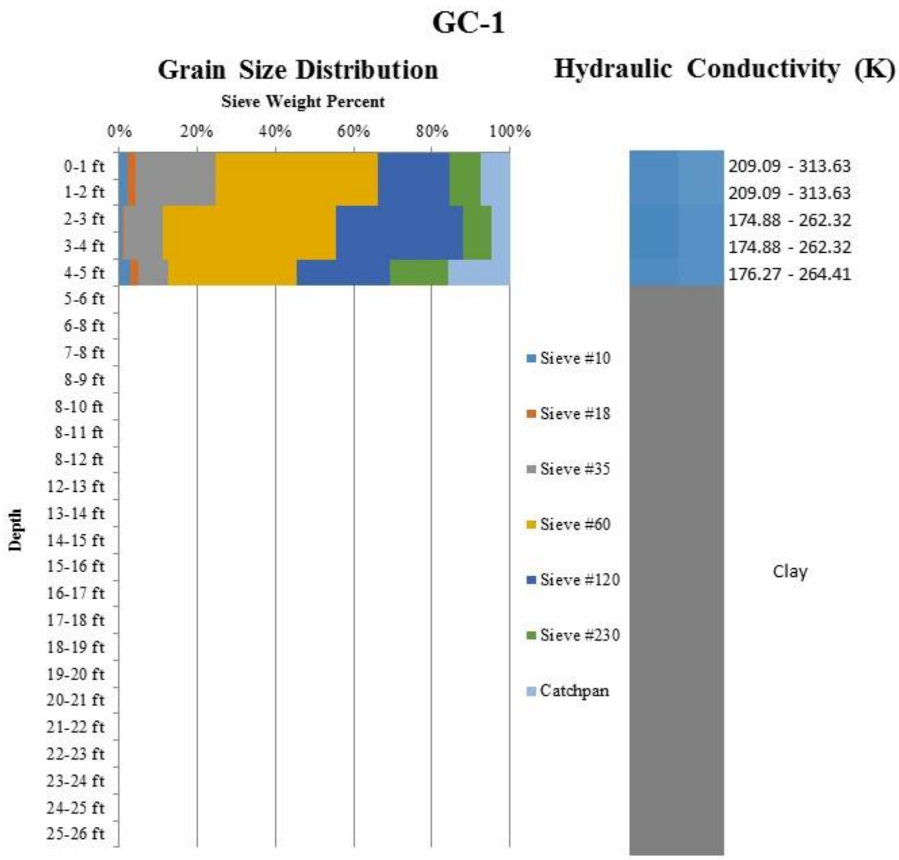


Figure 6.5 GC-1 Grain size distribution and hydraulic conductivity

Borehole 2 (GC-2) had 20 samples recovered, 8 of which contained clay and silt and could not be sieved. The intervals that could not be sieved were from 34-36 feet, and from 41-56 feet. From 0-1 foot, most of the sample was contained in sieve number 60 with a grain size of 0.025 mm. The majority of the borehole was contained in sieves 60 and 120 with grain sizes between 0.025mm and 0.0125mm. The average hydraulic conductivity ranges from 188 to 219 m/day and is as low as 85 m/day and is as high as 840 m/day. The average error for borehole 2 was a loss of less than 3.5 percent. The borehole interval containing the 4 to 8 foot sample had an error of over 36 percent. The error for this sample should be taken into account when reviewing the hydraulic conductivity.

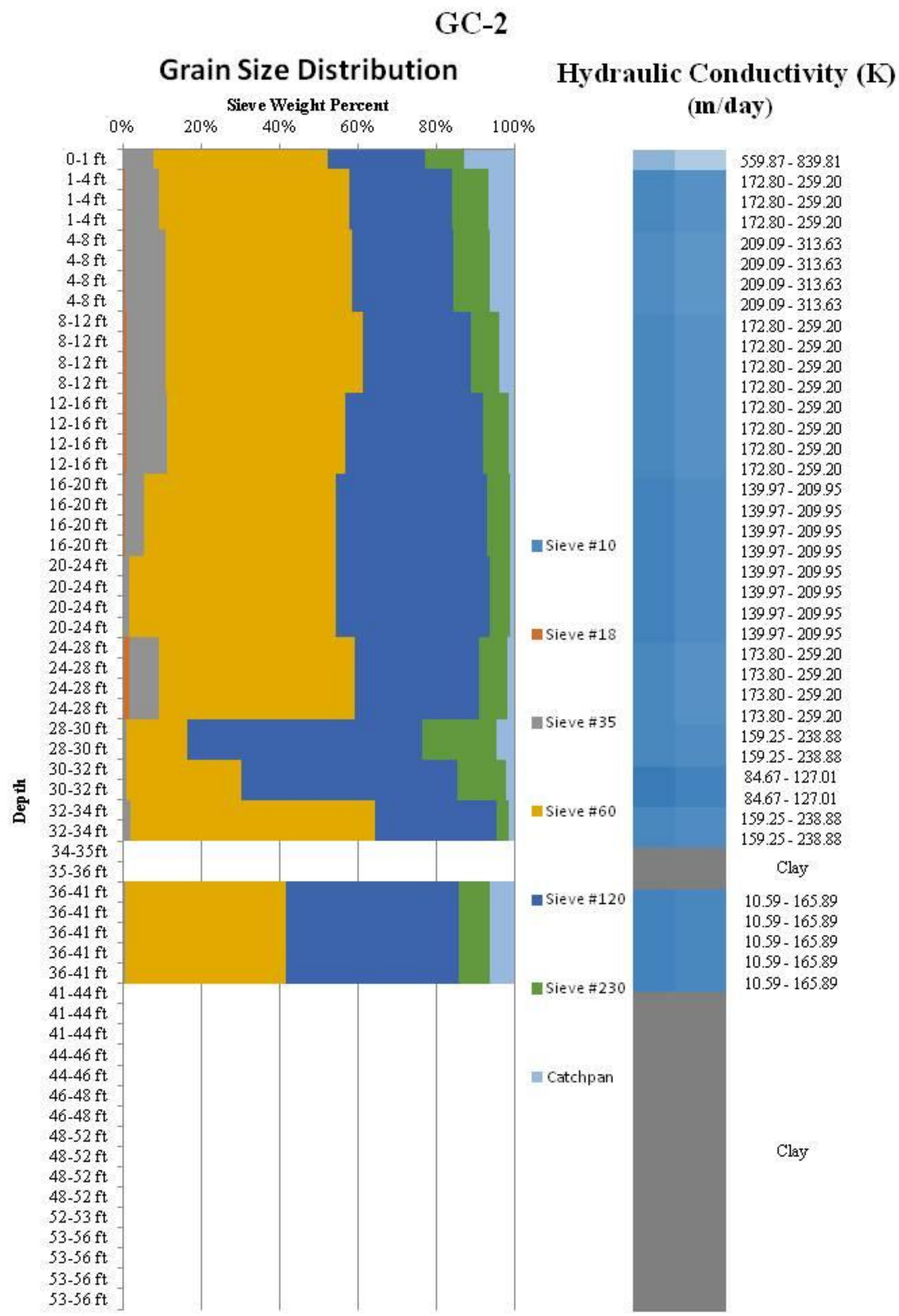


Figure 6.6 GC-2 grain size distribution and hydraulic conductivity

Borehole 3 (GC-3) returned 14 samples. The lower 8 samples contained clay and could not be sieved. The majority of the sediment from the first 6 samples was contained in sieve number 60, with an average grain size of 0.025 mm. The average error was less than 1.5%. The average hydraulic conductivity for borehole 3 is between 181 and 272 meters per day, as low as 73 meters per day, and as high as 399 meters per day.

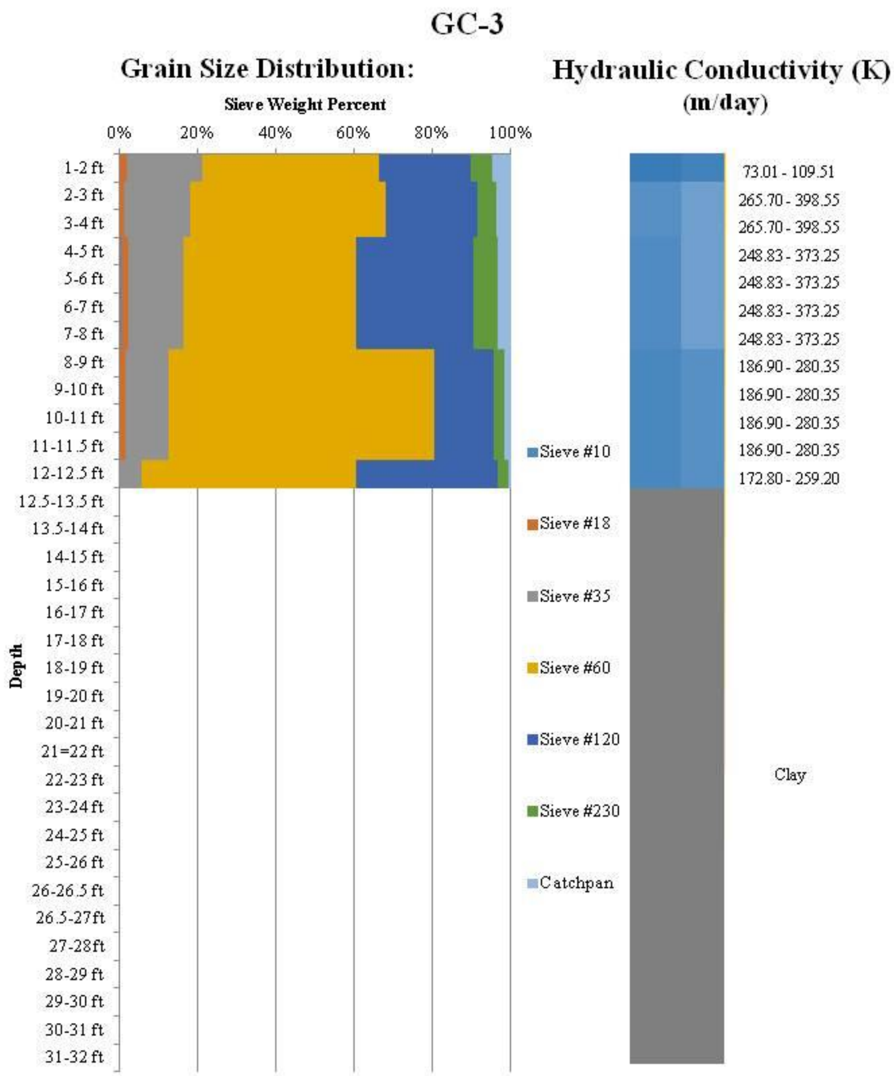


Figure 6.7 GC-3 grain size distributing and hydraulic conductivity

Three samples were recovered from borehole 13 (GC-4). The top one foot contained grass and topsoil. The majority of the sample contained clay and silt and could not be sieved. Three of the samples, however, contained sand. The average error for all of the samples from borehole 4 was about 11 percent with the 12 to 15 foot interval experiencing a loss of over 31percent of the sample. The majority of the samples were contained in sieve number 120, with a grain size of 0.0125 mm. The average hydraulic conductivity for the sand samples ranged from 63 to 95 meters per day with the lowest reported hydraulic conductivity equal to 43 meters per day and the highest equal to 127 meters per day.

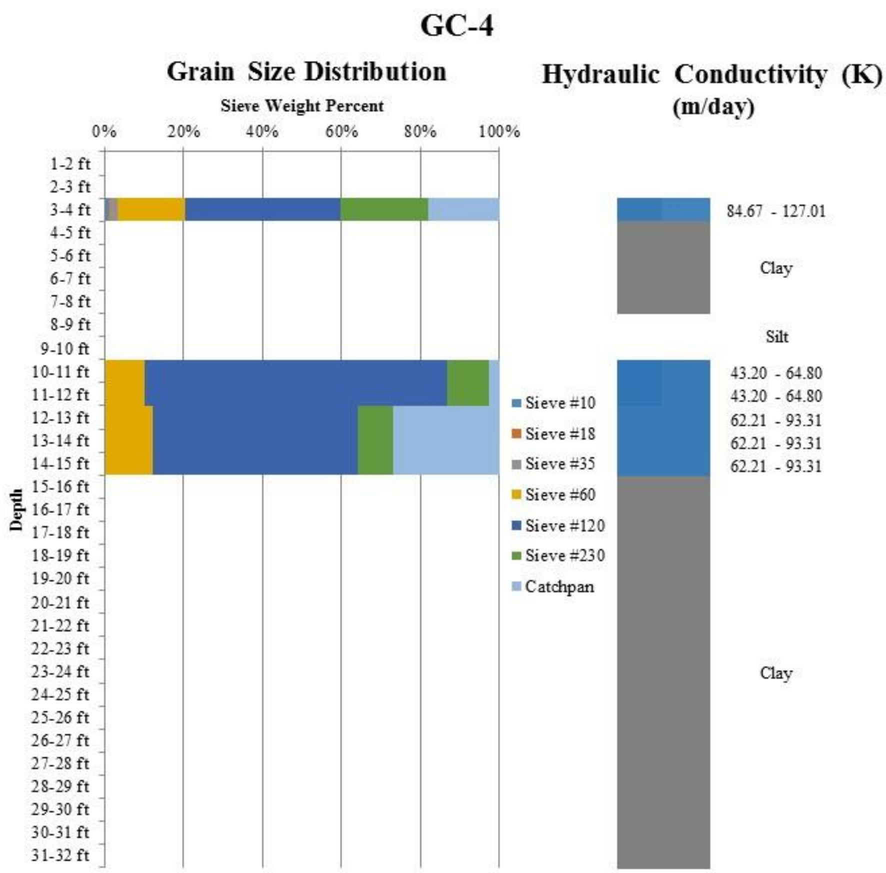


Figure 6.8 GC-4 grain size distribution and hydraulic conductivity

Borehole 5 (GC-5) returned nine samples. The first one-foot interval contained grass and topsoil. The lower four samples contained clay of varying color and could not be sieved. The majority of the sample was contained in sieve numbers 60 and 120 with grain sizes of 0.025 and 0.0125 mm respectively. The average error for borehole 5 was less than one percent. The average hydraulic conductivity for the entire borehole is between 166 and 249 meters per day. The lowest hydraulic conductivity found for the borehole was 95 meters per day and the highest was 452 meters per day.

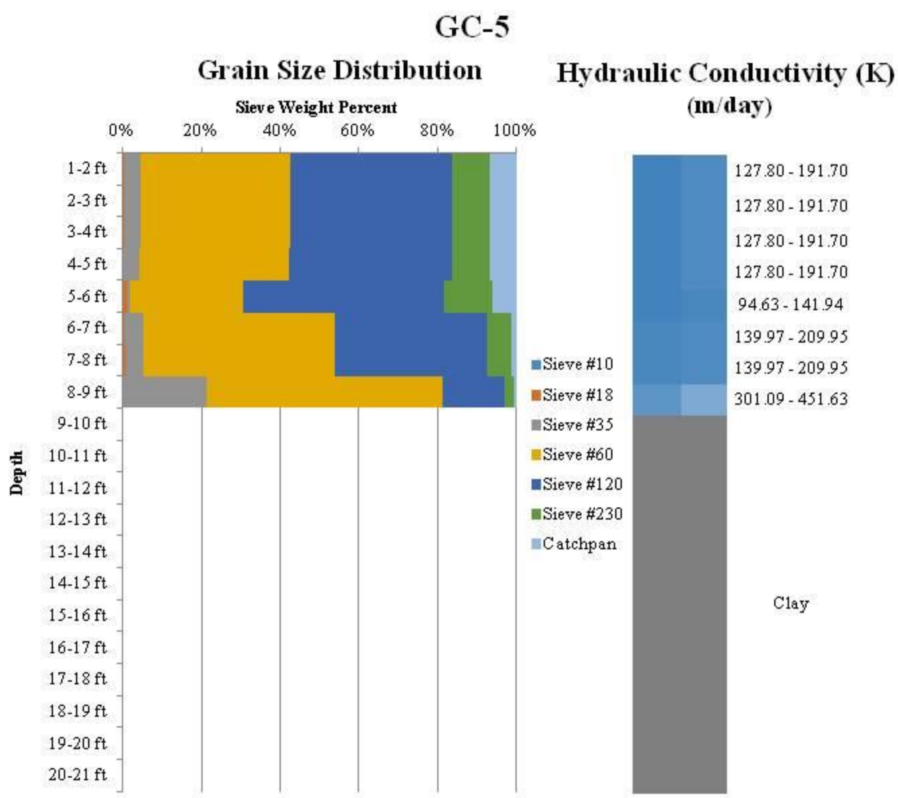


Figure 6.9 GC-5 grain size distribution and hydraulic conductivity

Borehole 6 (GC-6) returned 8 samples. The first one-foot interval contained grass and topsoil. The remaining sample intervals contained clay and silt, which could not be sieved. The geoprobe was pushed until refusal.

Borehole 7 (GC-7) returned 17 samples. The first one-foot sample interval contained grass and topsoil. The remaining 16 samples contained sand that ranged in color from orange-red to grey. The majority upper portion of the borehole sediment was contained in sieve number 60 with a grain size of 0.025 mm. The majority lower portion of the borehole was contained in sieve number 120 with a grain size of 0.0125 mm. The average error for the borehole was less than 2 percent sample loss. The 32 to 34 foot interval had the highest percent sample loss with an error of about 19 percent. The average hydraulic conductivity for borehole 7 was between 270 and 402 m/day. The lowest hydraulic conductivity reported was 80 m/day and the highest was 1396 m/day.

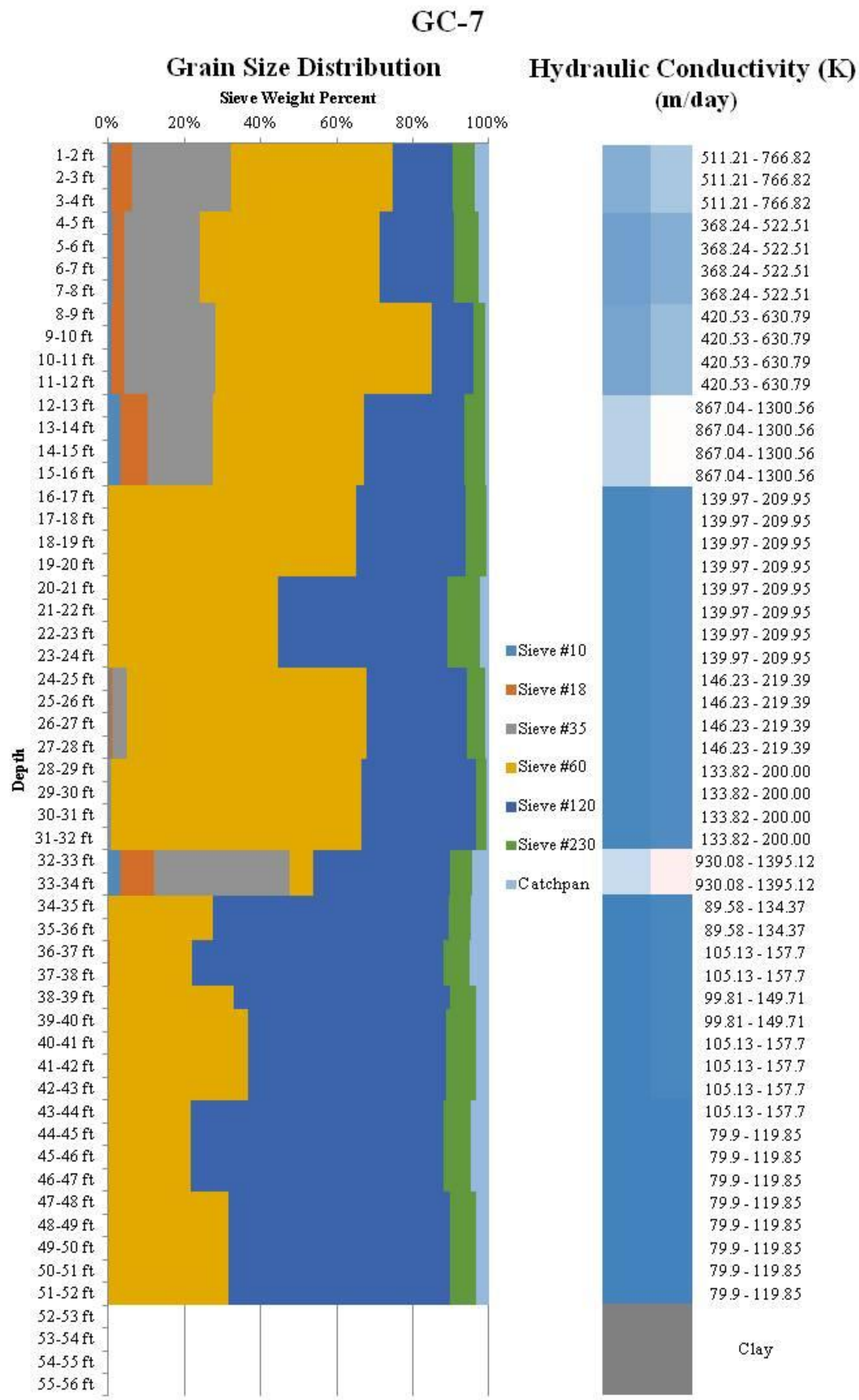


Figure 6.10   GC-7 grain size distribution and hydraulic conductivity for

Borehole 8 (GC-8) returned eight samples. The top one-foot interval of the borehole contained grass and topsoil, while the remaining seven samples contained sand ranging in color from tan to orange. The majority of the borehole sediments were contained in sieve number 60 with a grain size of 0.025 mm. The average error for borehole 8 was about 4 percent, with the 6 to 8 foot interval having the largest sample loss of 15 percent. The average hydraulic conductivity for borehole 8 is between 331 and 497 meters per day. The lowest hydraulic conductivity reported was 134 meters per day and the highest was 452 meters per day.

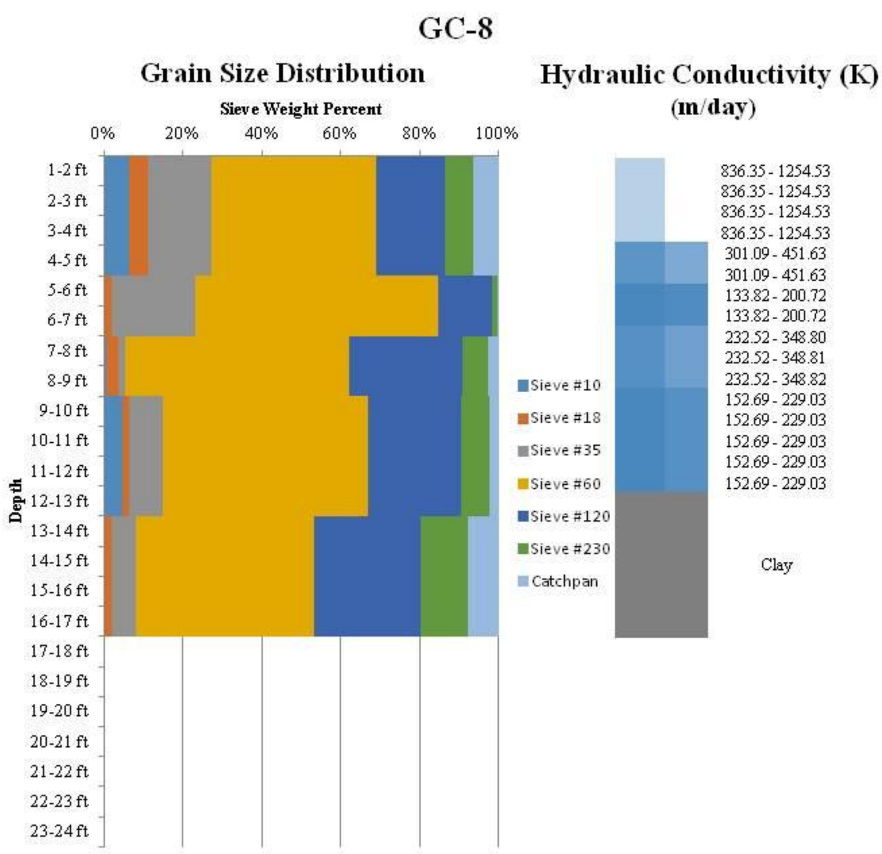


Figure 6.11 GC-8 grain size distribution and hydraulic conductivity

Borehole 9 (GC-9) was the deepest borehole, returning 26 samples, two of which contained clay. The majority of the upper one third of the borehole was contained in sieves 60 and 120 with grain sized 0.025 and 0.0125 mm respectively. The lower two thirds of the borehole were mostly contained in sieve number 60. The average error for borehole 9 was less than 1 percent. The average hydraulic conductivity for the entire borehole was between 348 and 523 meters per day. The lowest reported hydraulic conductivity was 37 meters per day and the highest was 3359 meters per day.

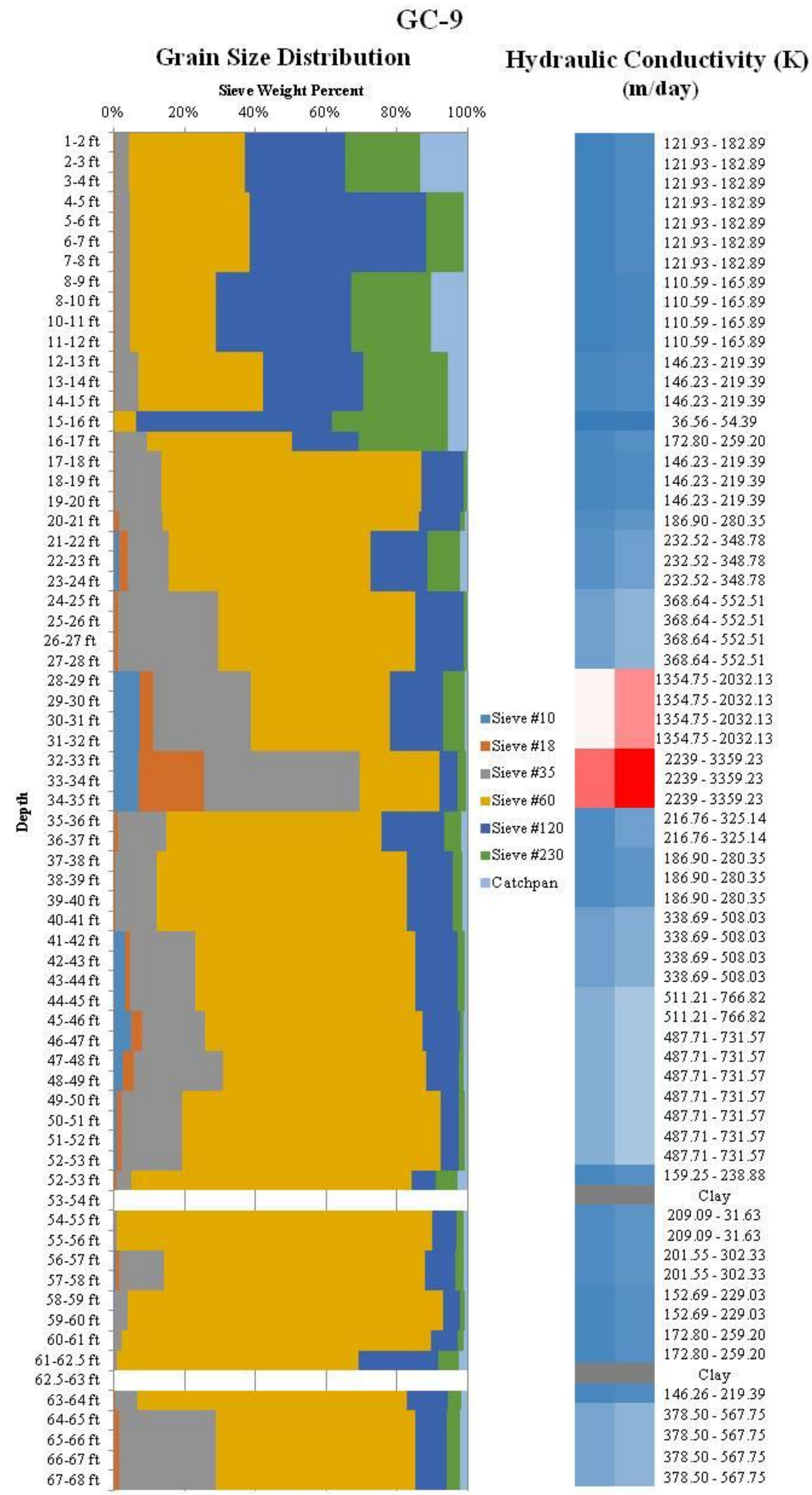


Figure 6.12 GC-9 grain size distribution and hydraulic conductivity

Borehole 10 (GC-10) returned six sample intervals, the first 2 feet of which contained grass and topsoil. Clay was found from 2 to 3.5 feet Sand ranging in color from grey to red with some orange made up the rest of the sample. The majority of the borehole was contained in sieve numbers 35, 60, and 120 with grain sizes 0.05, 0.025, and 0.0125 mm. The average error for the sample was less than 1% sample loss. The average hydraulic conductivity was between 522 and 783 meters per day, with the lowest hydraulic conductivity reported at 442 meters per day and the highest was 936 meters per day.

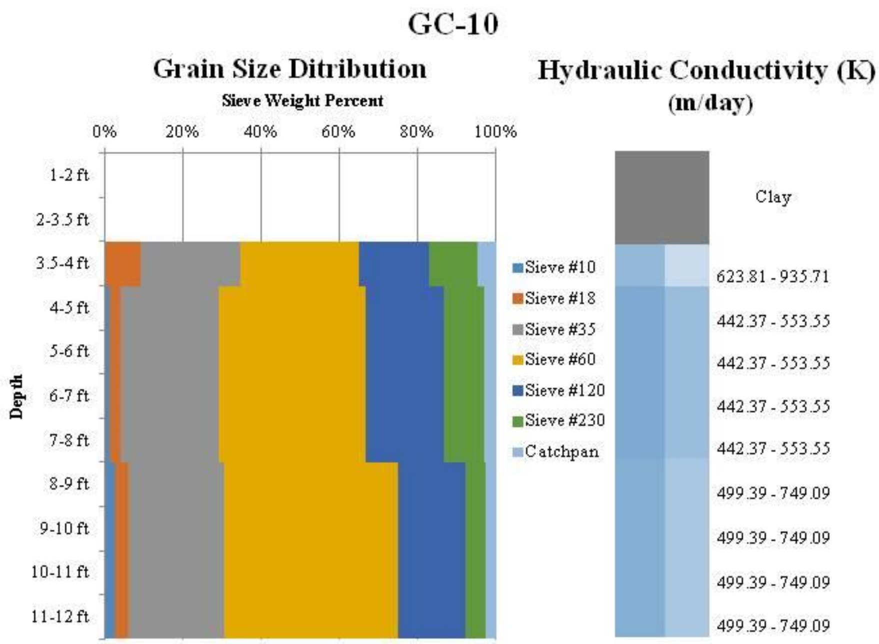


Figure 6.13 GC-10 grain size distribution and hydraulic conductivity

Sixteen samples were recovered from borehole 11 (GC-11). Grass and topsoil composed the first one-foot interval. Sand ranging in color from brown to orange to pink and tan composes a majority of the borehole. Grey clay is found throughout. The majority of the borehole sediments were contained in sieve number 120, with a grain size of 0.0125 mm. The average error was less than 1 percent. The average hydraulic conductivity was between 106 and 158 meters per day. The lowest hydraulic conductivity reported was 43 meters per day and the highest was 749 meters per day. The hydraulic conductivity is high at the top of the borehole. Clay layers are next, and the hydraulic conductivity decreases after the clay layers significantly.

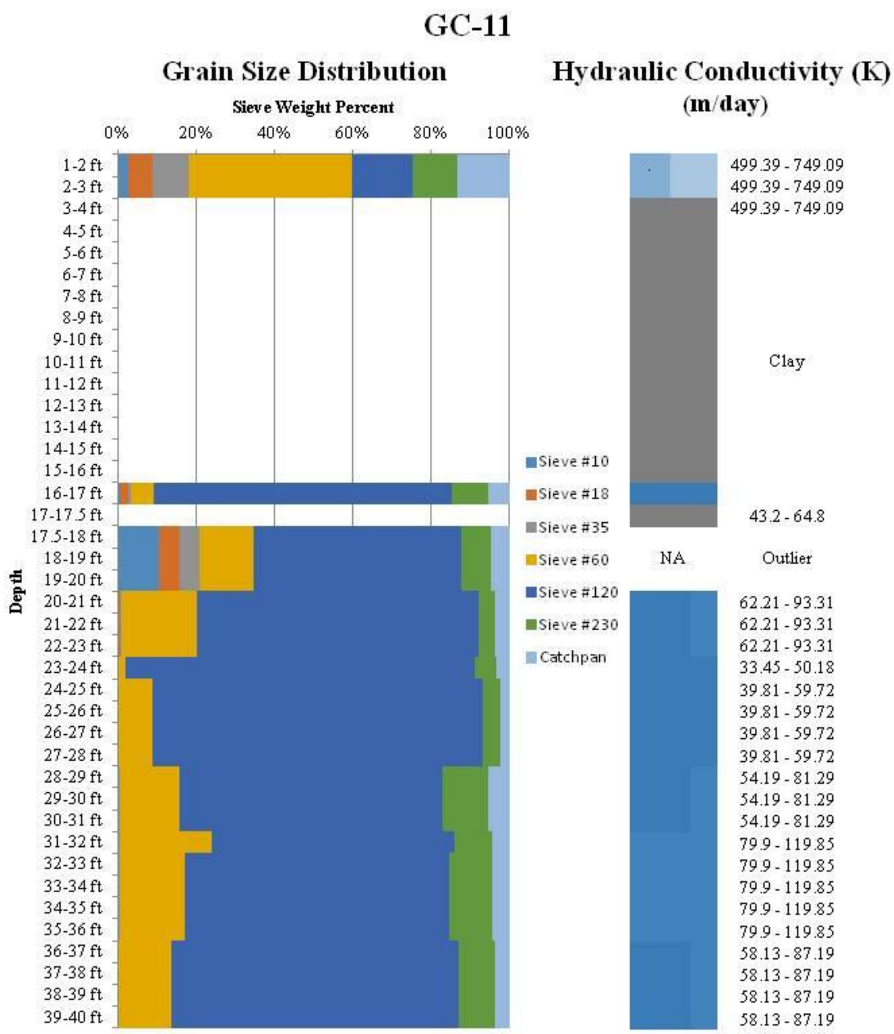


Figure 6.14 GC-11 grain size distribution and hydraulic conductivity

Borehole 12 (GC-12) returned 26 samples. The top one-foot contained grass and topsoil. Sand composed the following intervals up to the depth of 15 feet. Clay, ranging in color from yellow to grey with some orange was found to a depth of 44 feet Orange, yellow, and grey sand was found at the bottom of the borehole. The majority of the borehole was contained in sieves 60 and 120 at the top and in sieve 60 at the bottom. The average error was less than one percent sample lost during the analysis. The average hydraulic conductivity of the sand layers contained in borehole 12 was between 199 and 299 meters per day. The lowest recorded hydraulic conductivity was 43 from the sand layer between the two clay layers. The highest hydraulic conductivity recorded was 749 meters per day above the clay.

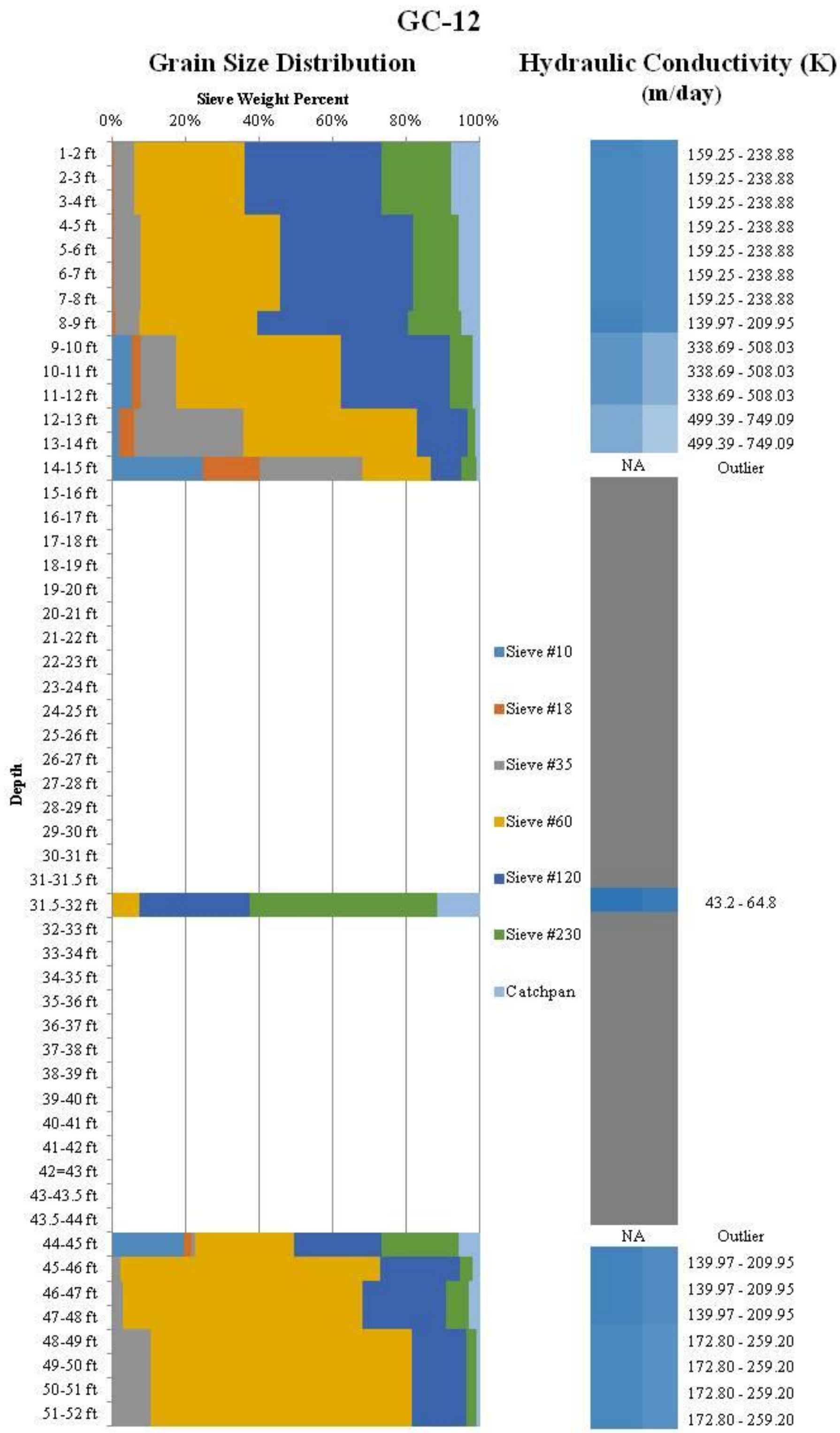


Figure 6.15 GC-12 grain size distribution and hydraulic conductivity \

Twenty samples were recovered from borehole 13 (GC-13). The first one foot contained grass and topsoil. Sand of various colors composes the upper two thirds of the borehole. Clay composes the lower one third and was not sieved. A sand layer is under the clay. The majority of the upper two thirds of the borehole were contained in sieve numbers 35 and 60, with grain sizes of 0.05 and 0.025 mm respectively. The average error was less than 1 percent sample lost. The average hydraulic conductivity for the borehole ranges from 749 to 1124 meters per day. The lowest reported hydraulic conductivity is 43 meters per day at the bottom of the borehole, under the clay. The highest hydraulic conductivity is 3175 meters per day.

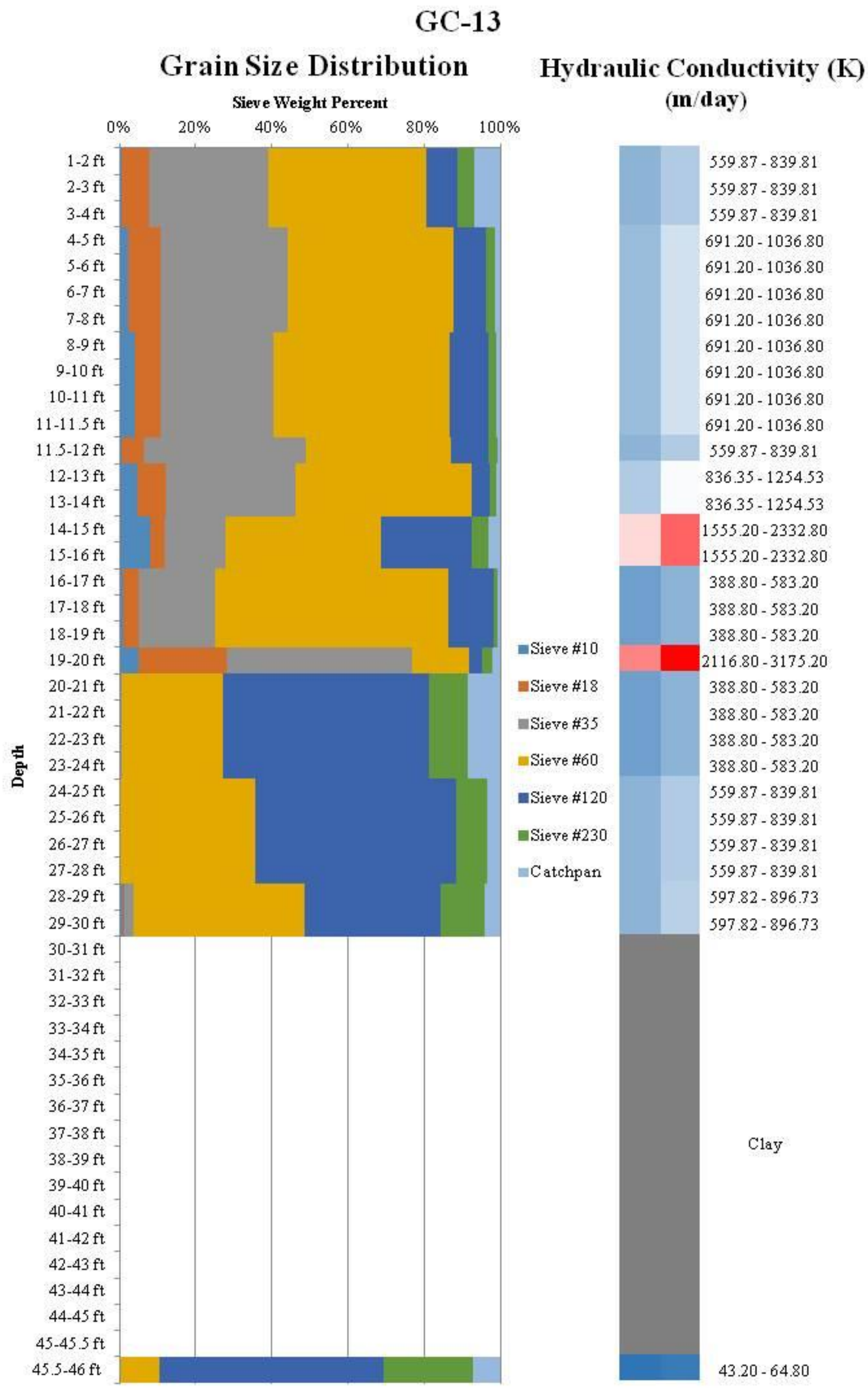


Figure 6.16 GC-13 grain size distribution and hydraulic conductivity

CHAPTER VII

DISCUSSION

This study is the first of its kind within the study area with the implementation of a grain size analysis to gain an understanding of how water moves through the subsurface in the Pascagoula River Basin.

7.1 Surface-Water and Groundwater Interactions

7.1.1 Pascagoula River Basin

The purpose of this portion of the study was to determine the quantity of water that contributes to baseflow within the stream reach. The hypothesis was that the amount of water that contributes to baseflow changes throughout the stream reach, which could allow for the loss of water along the stream reach. The analysis of the stream reach showed that baseflow decreases as water moves from Okatibbee Lake and then increases again before the water reaches Pascagoula. The change in baseflow contribution suggests that, depending upon the depth to the groundwater table, enough water could be lost to bank storage during times of low flow that it could be noticeable downstream. This supports the original hypothesis.

To improve the resolution of this analysis, more continuous-monitoring stations could be implemented to increase the number of discharge recording points along the stream. The sites used, however, were limited due to availability of data but were located after the confluences of major tributaries. While the number of continuous-monitoring sites was limited, the locations accounted for discharge contributions of major tributaries throughout the stream reach. The contribution from the major tributaries is apparent in the discharge scale of the hydrographs in Appendix A.

The recursive digital filter used with the WHAT online resource returned inconclusive results for station 02479000, producing baseflow readings that appeared to be zero even when there was sufficient streamflow. Because of this, the results from the recursive digital filter are not reliable for this study. The focus should remain on the other three parameters used. The recursive digital filter does, however, show a similar trend in baseflow from Okatibbee Lake to Pascagoula. The hydrograph recession-analysis method used to estimate baseflow should be chosen according to parameters relevant to the study and the availability of stream discharge data.

7.1.2 Cedar Creek Basin

The analysis of the Cedar Creek Basin was in response to the research questions that pertained to reservoir fill time. The research questions aimed to understand how long the reservoir would take to fill based on the hydraulic conductivity at the locations of the proposed reservoirs. The hypotheses associated with the research questions were that the locations of the proposed reservoirs were on top of sediments that have a high hydraulic conductivity, which would cause the reservoir to fill slowly. The term slow is relative and specific to the area.

The grain-size analysis conducted on the thirteen boreholes drilled by Pickering Firm, Inc. were sieved by hand using a standard set of sieves. To limit human error, a Ro-Tap machine or similar should be used to conduct a grain-size analysis. The scale used to weigh the sand samples was also past the due date for calibration. The error percentages for the difference in mass of the sand samples also returned near zero or positive values. This may be a result of the high humidity during the sieving process. The humidity for each day samples were sieved is reported in Table 7.1. To minimize re-absorption of moisture, the samples were exposed to the air for the shortest amount of time possible to accurately possess the sample.

Table 7.1 Humidity for each day samples were sieved

Date	Humidity		
	High (%)	Average (%)	Low (%)
10/09/2014	100	77	40
10/10/2014	100	84	55
10/11/2014	100	84	45
10/12/2014	100	88	70
10/13/2014	94	89	70
11/22/2014	100	68	37
11/23/2014	100	95	82

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Overall, the hydraulic conductivities concluded from each grain size analysis shows that the permeability of the sands within the unconsolidated sediment are relatively high, upwards of hundreds of meters per day. The relatively high permeability of the sands suggests that, as the water level rises, a considerable amount of water will move into the subsurface and contribute to the groundwater system until the new surface-water level created by the proposed reservoirs reaches equilibrium. In addition, the groundwater level will change relatively quickly in response to precipitation events and water releases from the reservoir. Since the ground will need to saturate, and the ground could hold a large amount of water compared to a reservoir located in a more clay-like or consolidated sediment setting, the reservoir will fill more slowly. The analyses within the Cedar Creek Basin proved the hypothesis that the location for the proposed reservoirs contains unconsolidated sediments. To confirm if the proposed reservoirs will fill at a fast or slow rate, further analysis and modeling are needed.

The same baseflow analysis was conducted within the Cedar Creek Basin as on the entire Pascagoula River Basin using a digital filter. The results from the baseflow analysis within the Cedar Creek Basin give a large range for the baseflow component. The analysis also returned the same results for both parameters of the one parameter digital filter. This suggests that on a small scale of a few years either of the two parameters used in the one parameter digital filter can be used. To better understand the baseflow component within the Cedar Creek Basin, more continuous monitoring sites could be analyzed.

CHAPTER VIII

CONCLUSION

This study focused on the groundwater and surface-water interactions of two components within the Pascagoula River Basin, located in southeast Mississippi: the main stream reach from Okatibbee Lake to Pascagoula, and the site of two proposed reservoirs in George County. Daily stream discharge data was analyzed to determine the baseflow contribution in the main stream reach. Continuous monitoring sites (CL-3 and CB-5) located within the Cedar Creek Basin, as well as borehole samples from the perimeter of the proposed reservoirs were used to analyze the groundwater and surface-water interactions at the proposed reservoir sites in George County.

Within the main stream reach, the study found with the use two hydrograph baseflow-recession estimation programs, that the baseflow component of the streamflow is between about 50 and 70 percent. The baseflow component varies seasonally and also decreases as the water flows from the headwaters and increases again when the water reaches Pascagoula. The decrease in baseflow could suggest that water could be lost to bank storage during times of low flow in the basin.

At the site of the proposed reservoir, the grain-size analysis of 13 borehole samples found that there are unconsolidated sediments composed of sands, clays, and silts. The hydraulic conductivity of the sediments ranges from about 40 meters per day to as high as several hundreds or thousands of meters per day. The high hydraulic conductivity of the sediments will allow water to move to bank storage as the proposed reservoir fills. Likewise, should the reservoir be drained, a considerable amount of water would drain from bank storage.

The motivation for this study was provided by the need to manage fresh-water resources to help maintain stream ecology downstream, as well as for industrial and recreational use. In the year2000, Chevron and Mississippi Power purchased four billion gallons of water from the Pat Harrison Waterway District which operates the dam on Okatbbee Lake to provide enough water to keep the industries going to avoid a negative economic affect in the region if the companies were to shut down temporarily. Once the water was released, not all of the purchased water reached the destination. The water loss prompted an interest in the groundwater and surface-water interactions of the Pascagoula River Basin. Two reservoirs have been proposed for construction in George County, Mississippi as well to not only help maintain stream ecology downstream during low flow, but increase surface-water storage and deliver water more rapidly.

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APPENDIX A

HYDROGRAPHS: PASCAGOULA RIVER BASIN

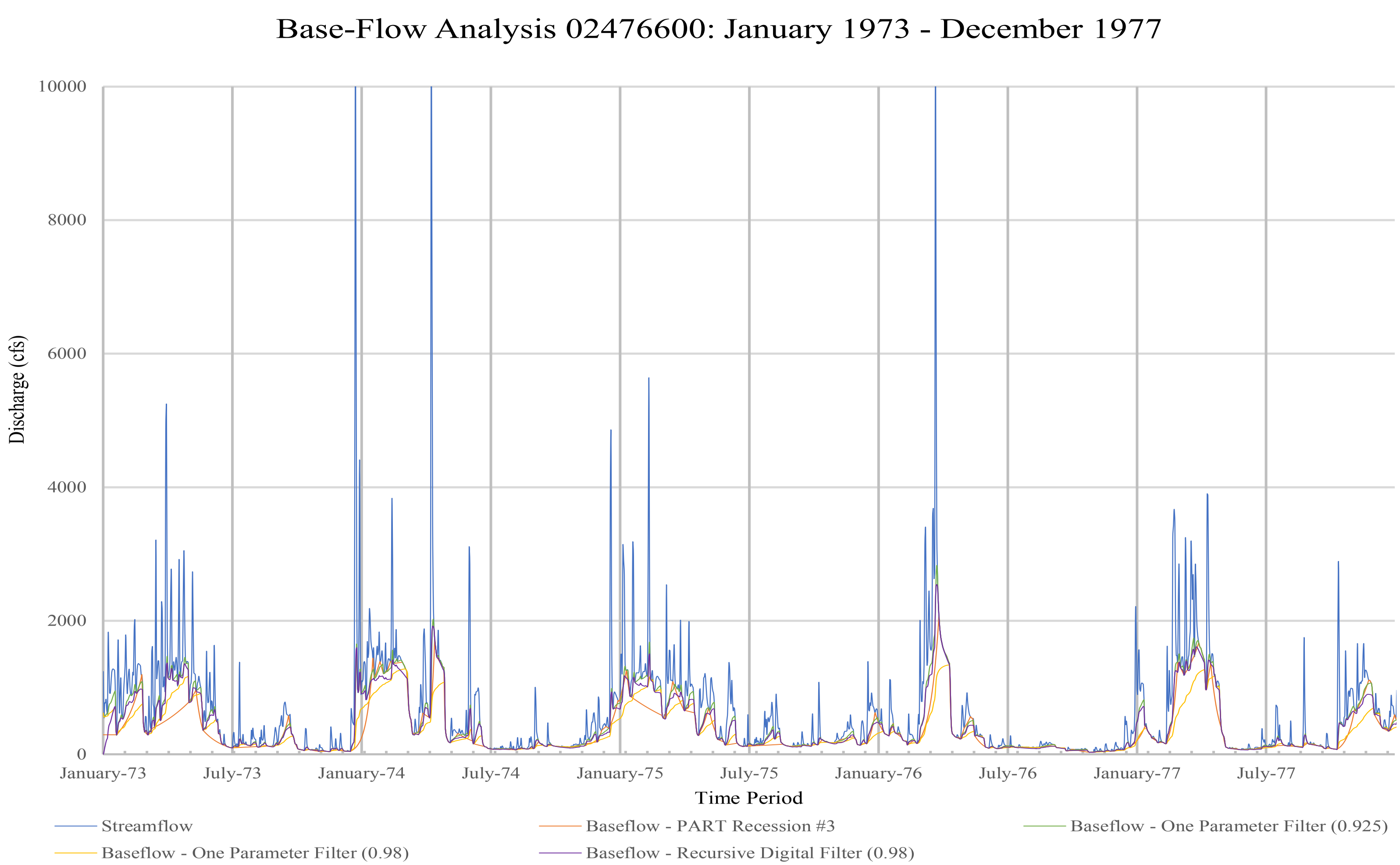
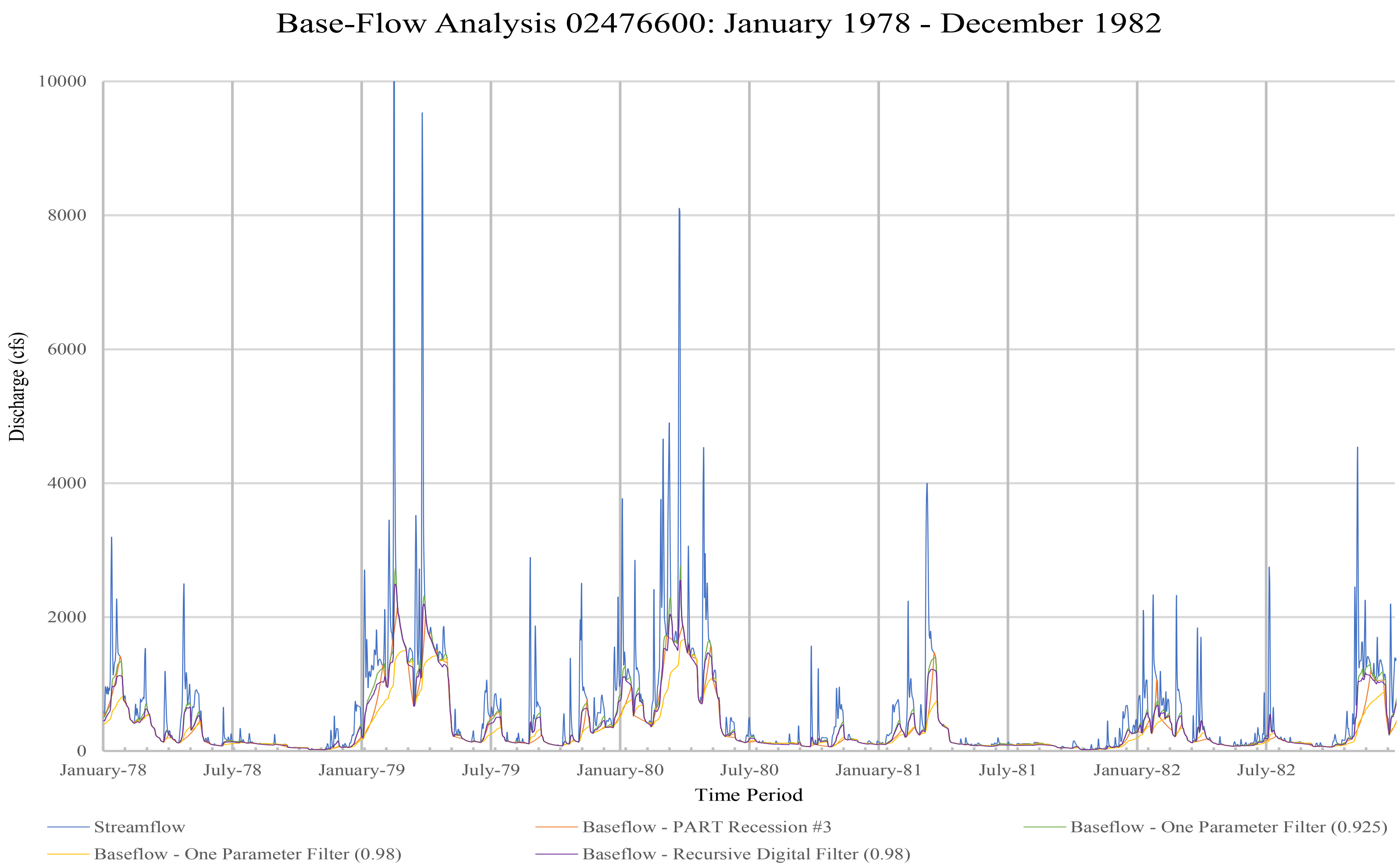


Figure A.1 02476600 January 1973 to December 1977



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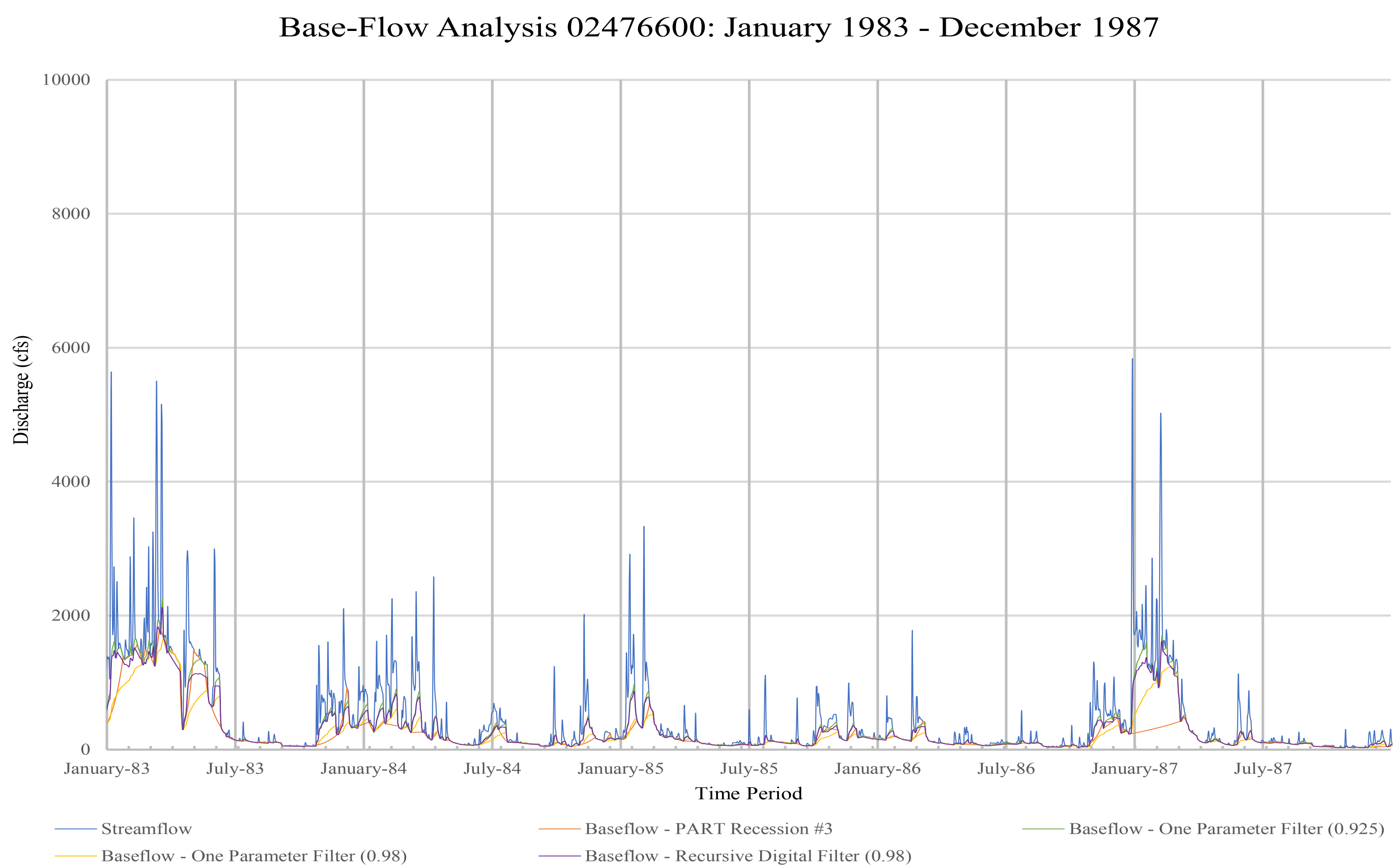

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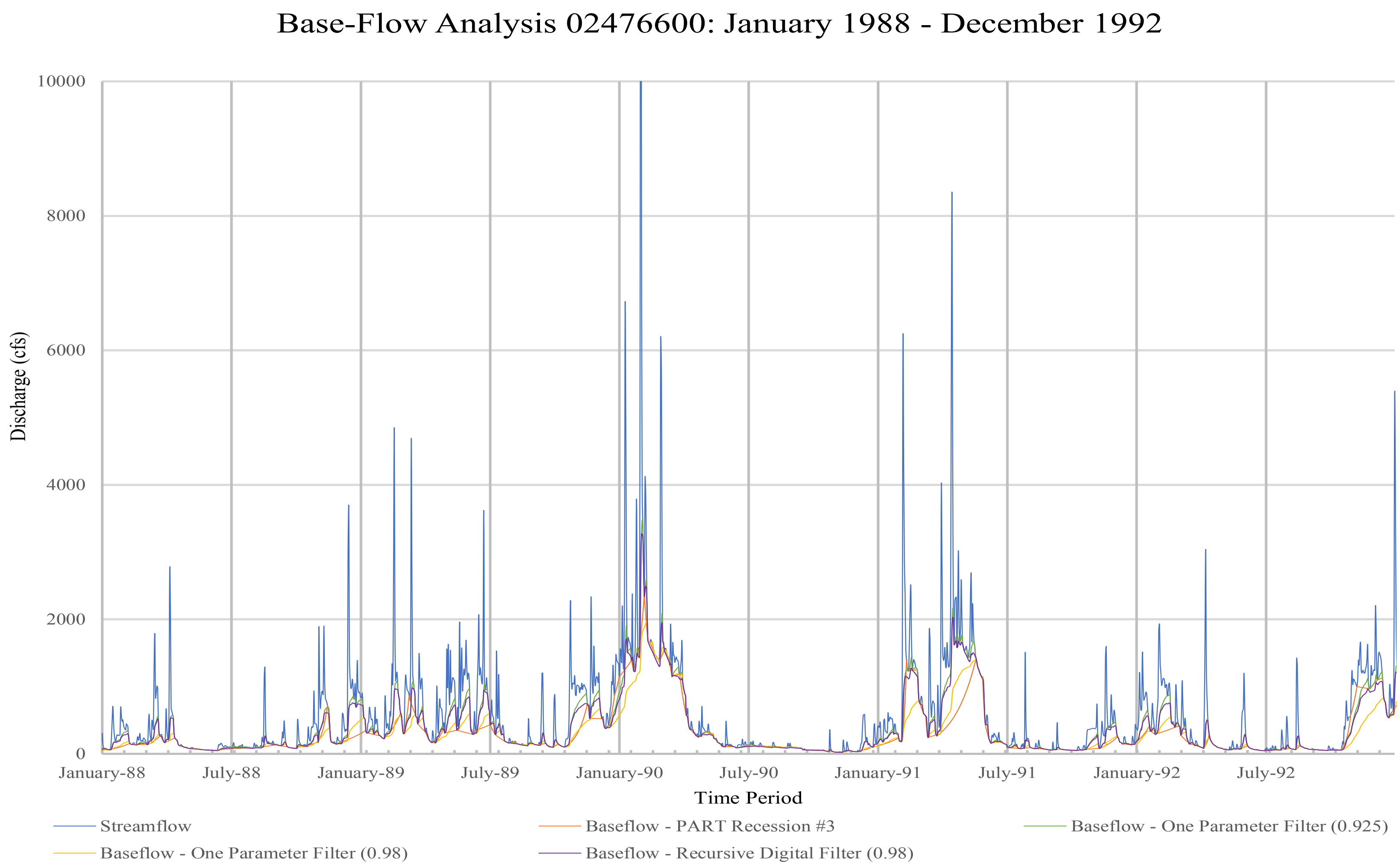

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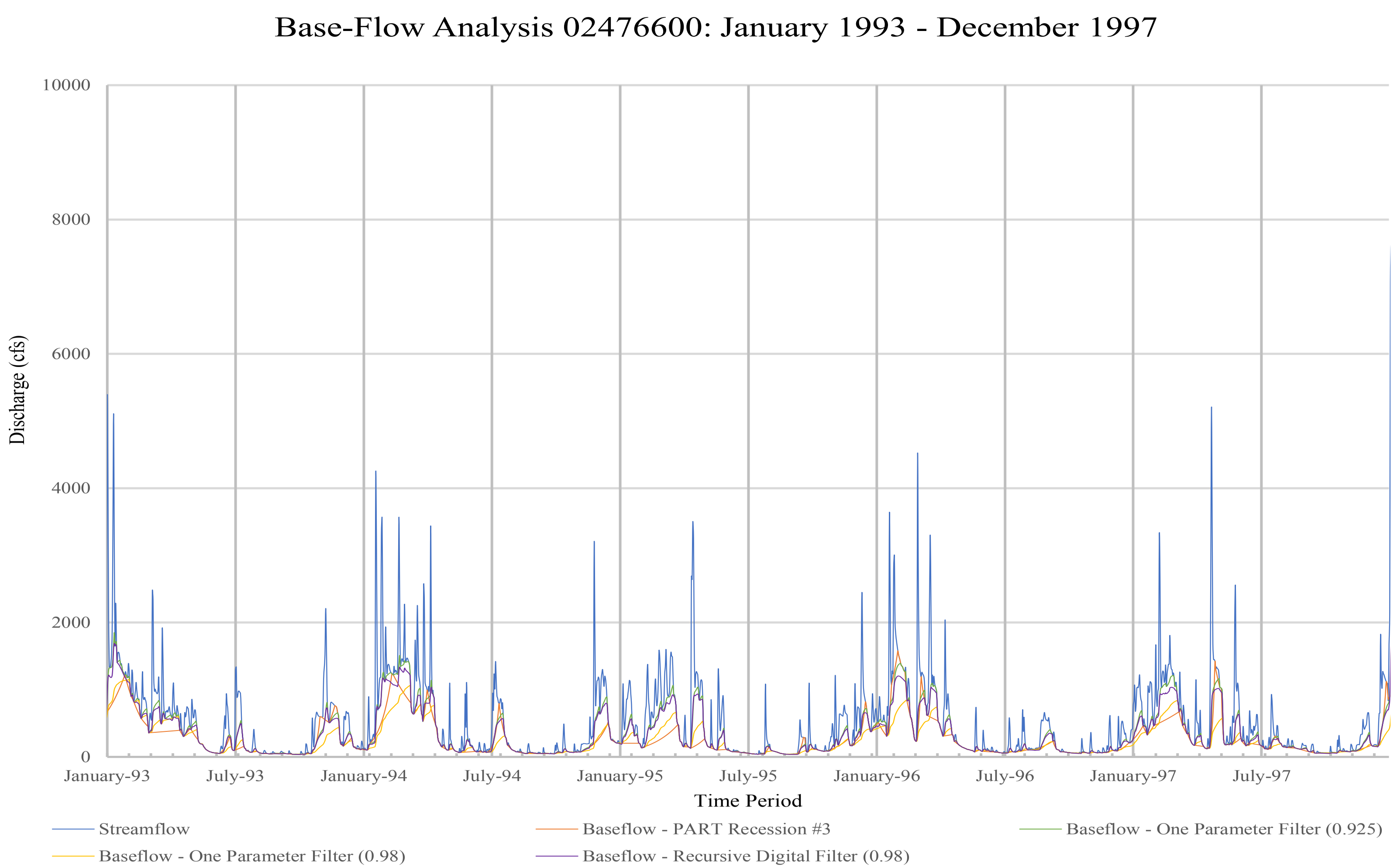

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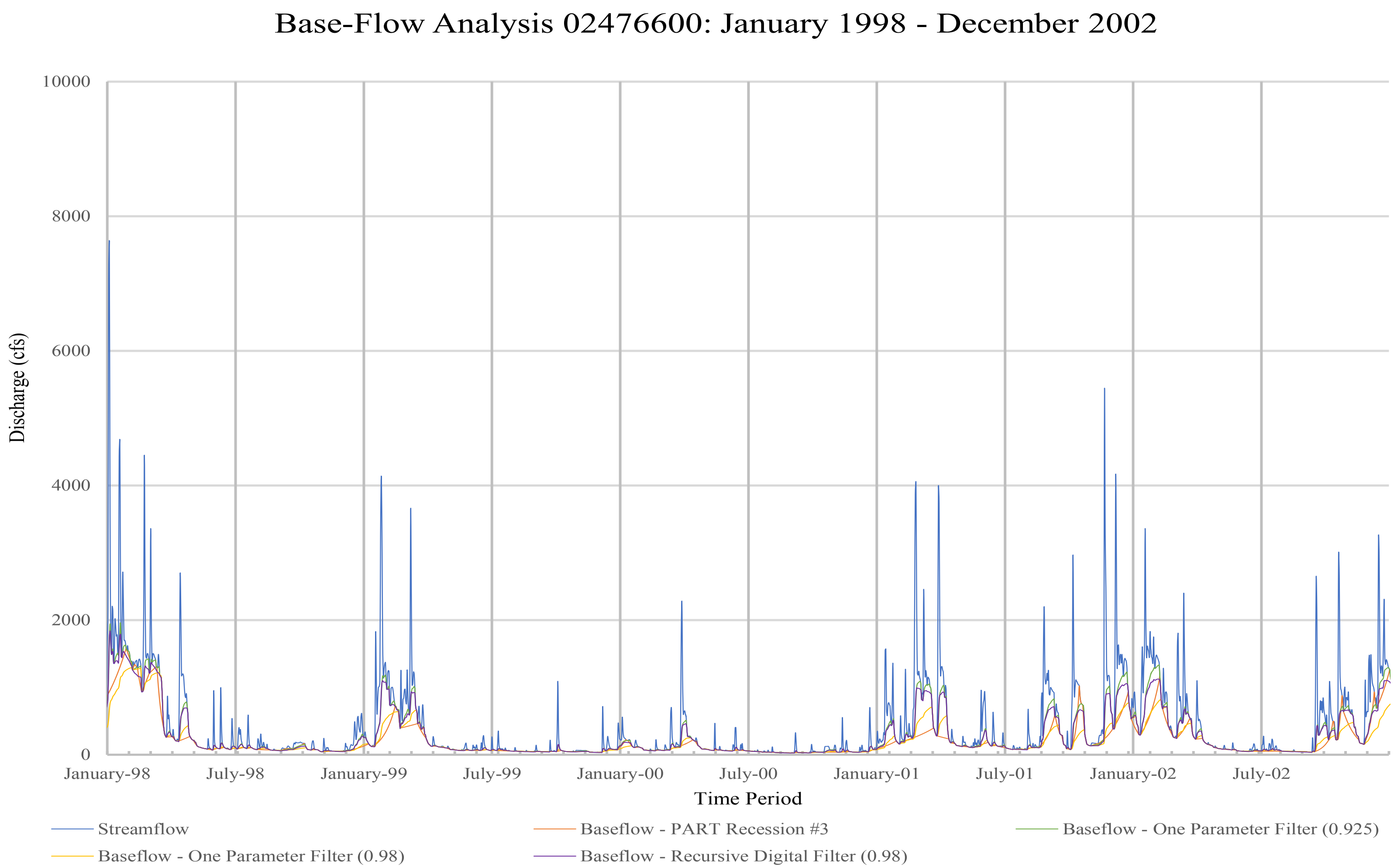

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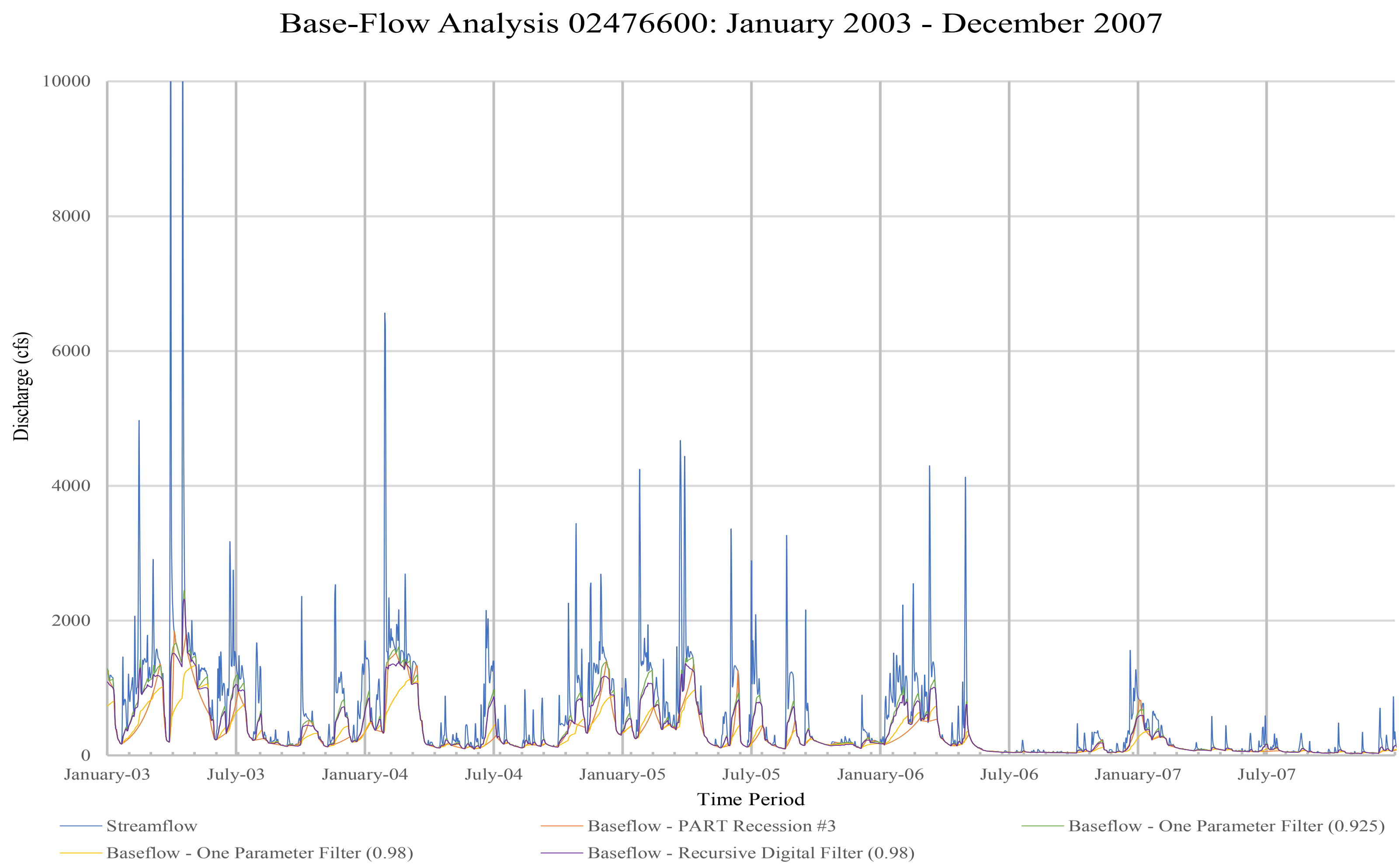

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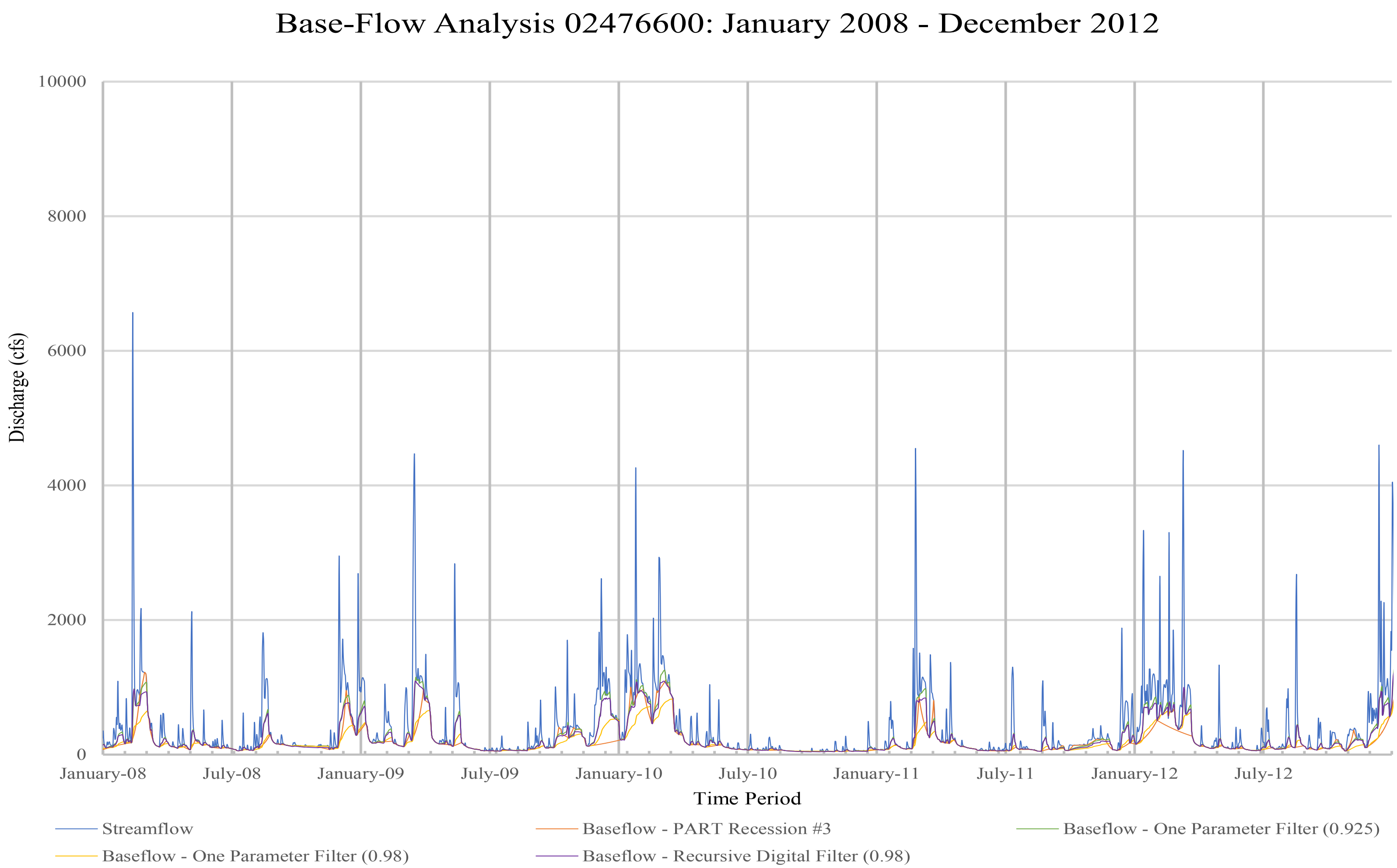

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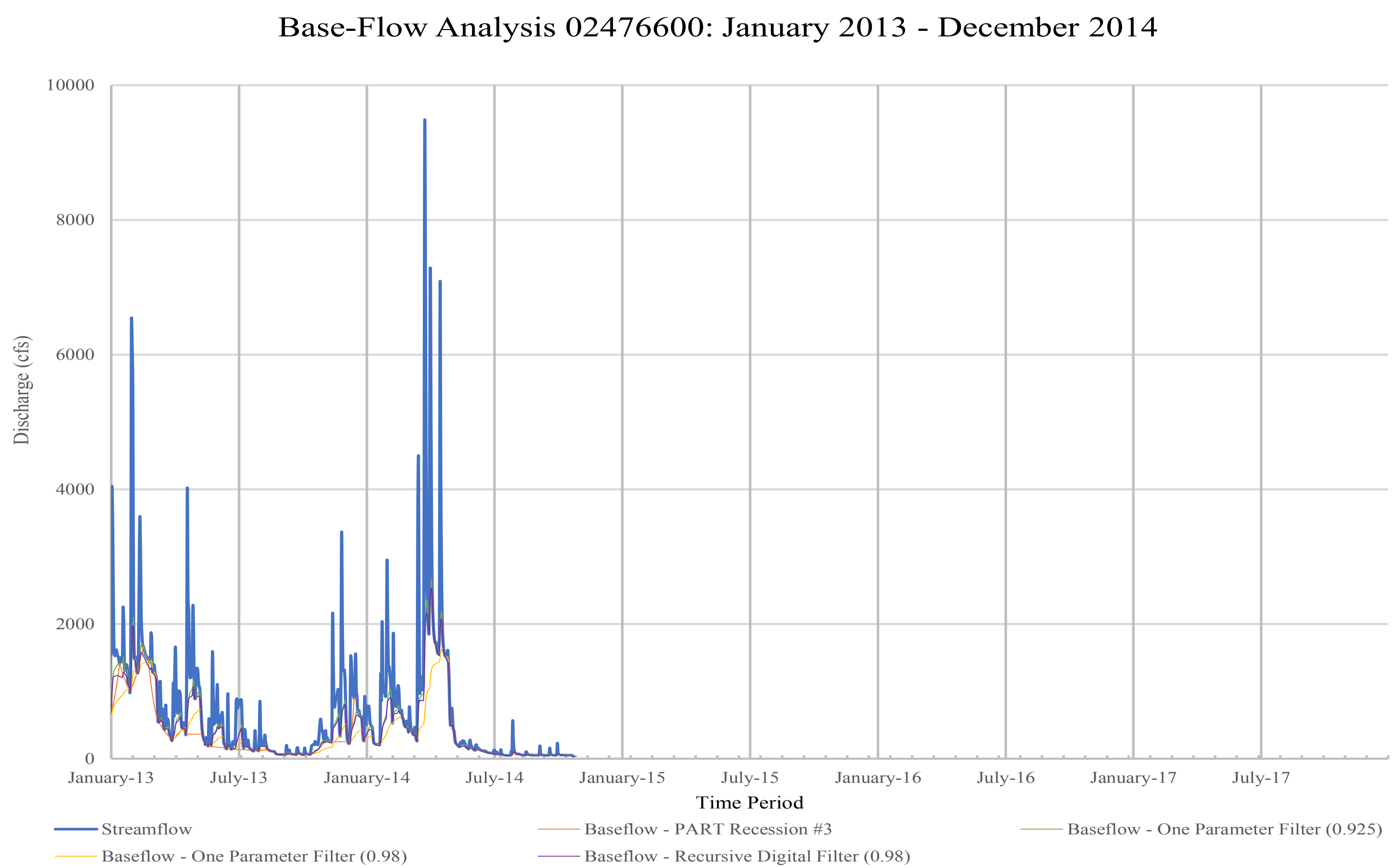

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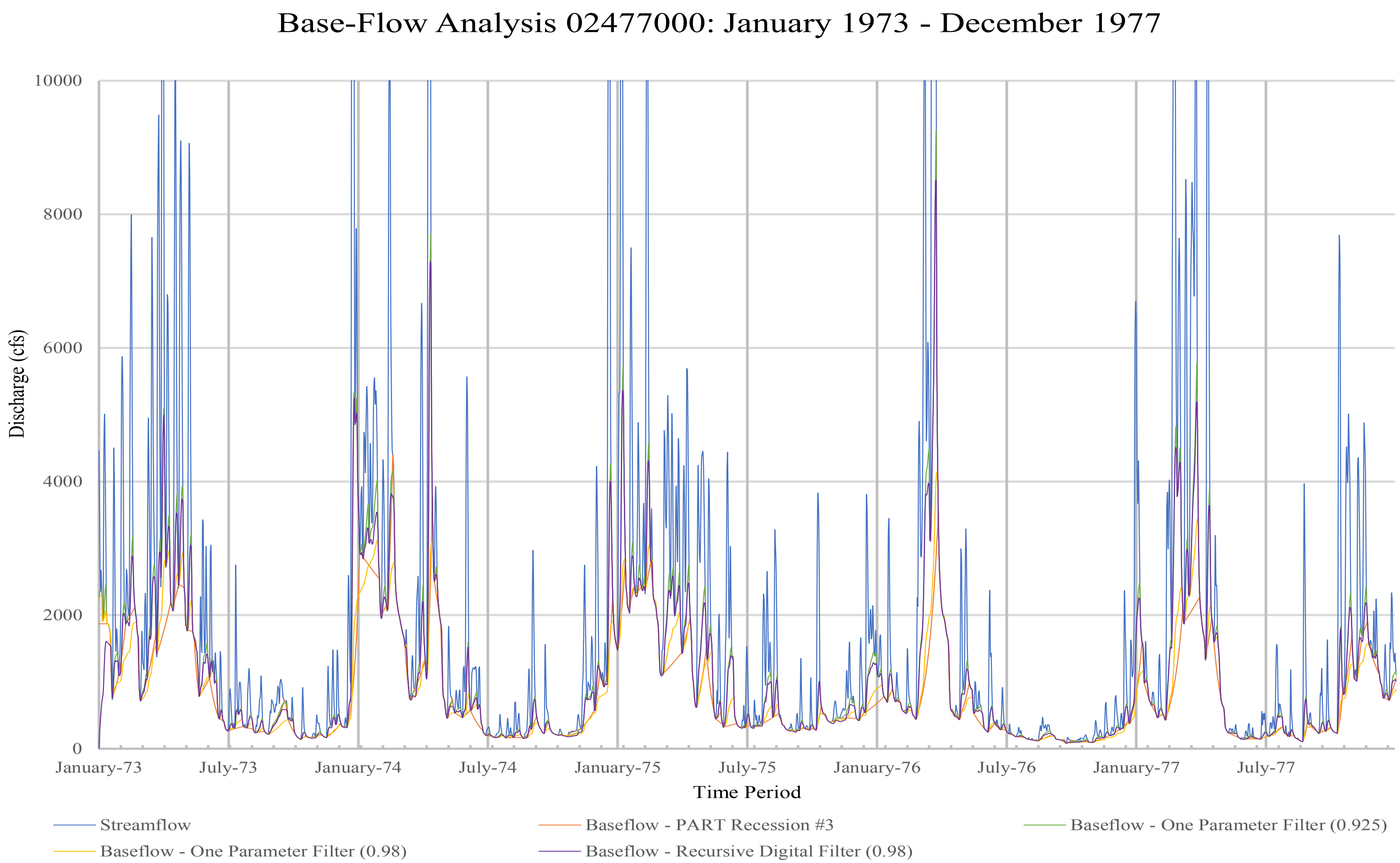

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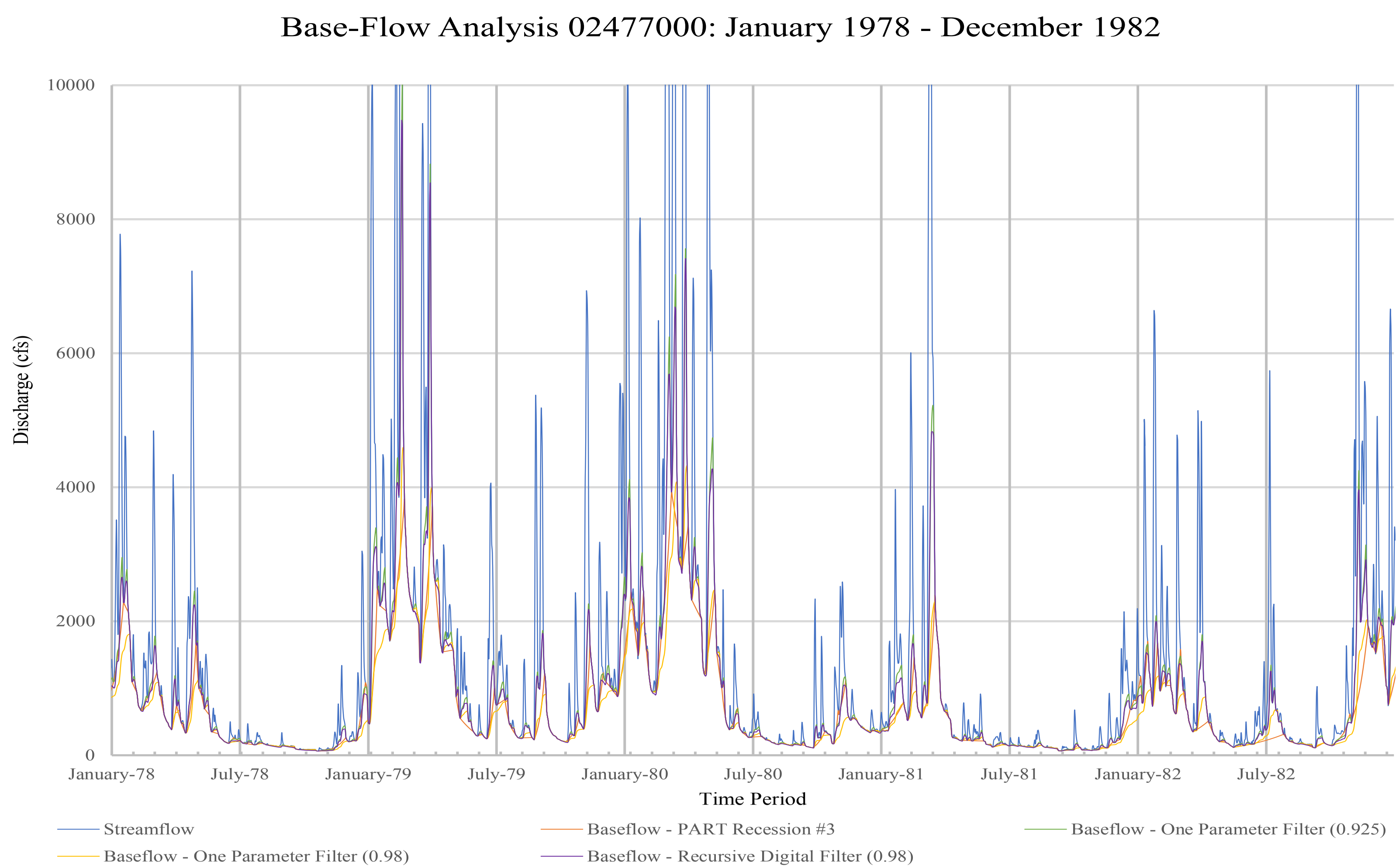

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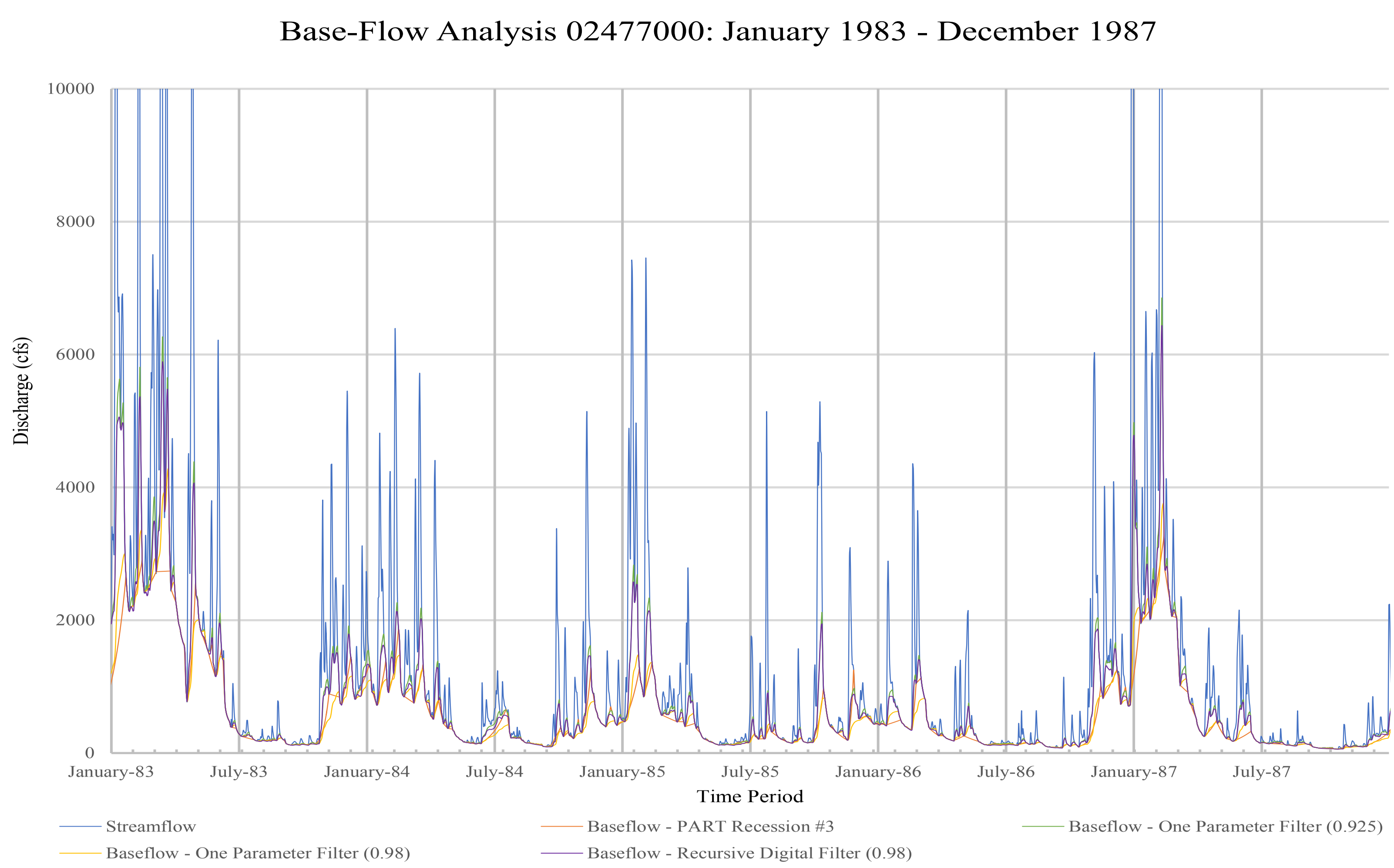

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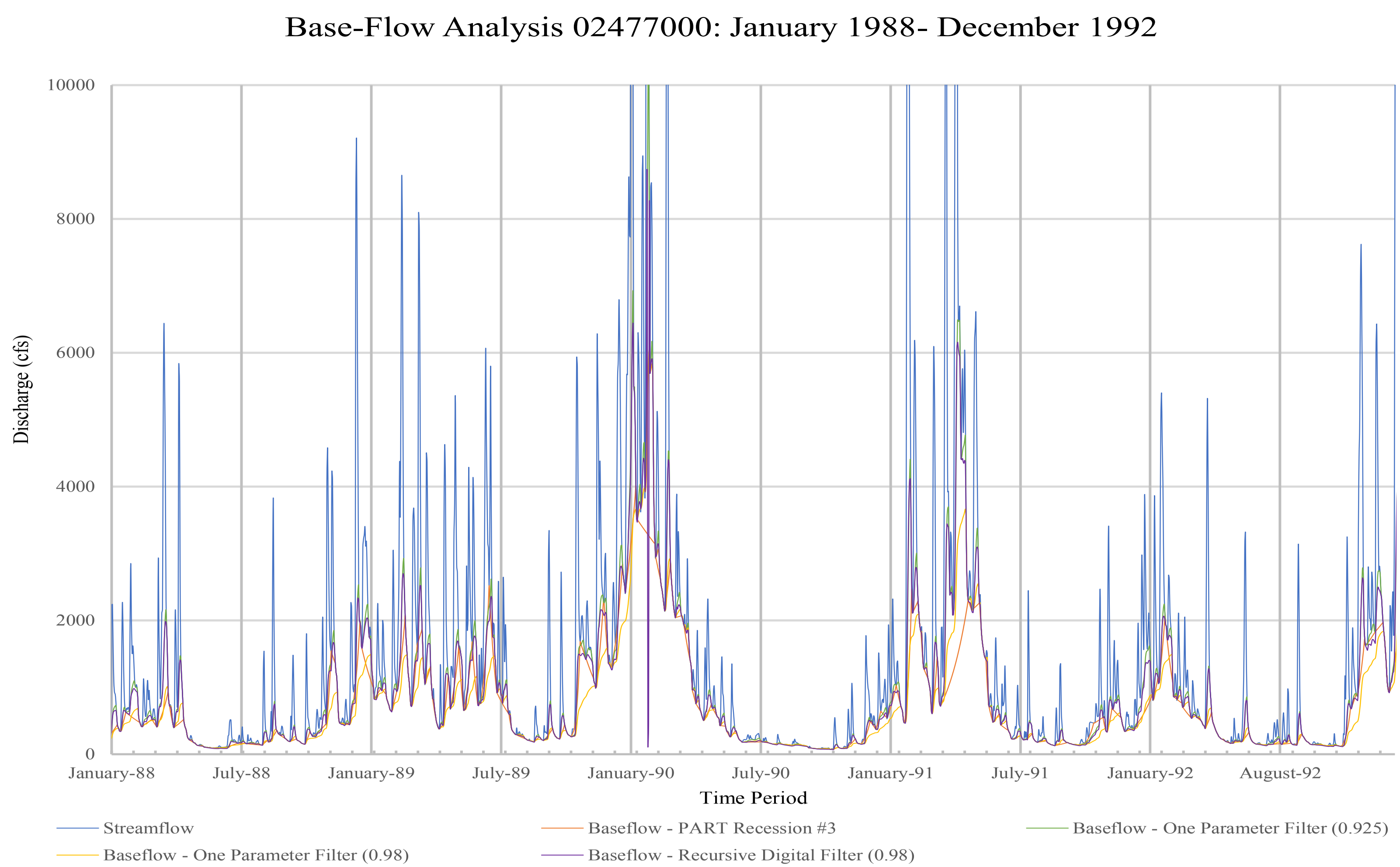

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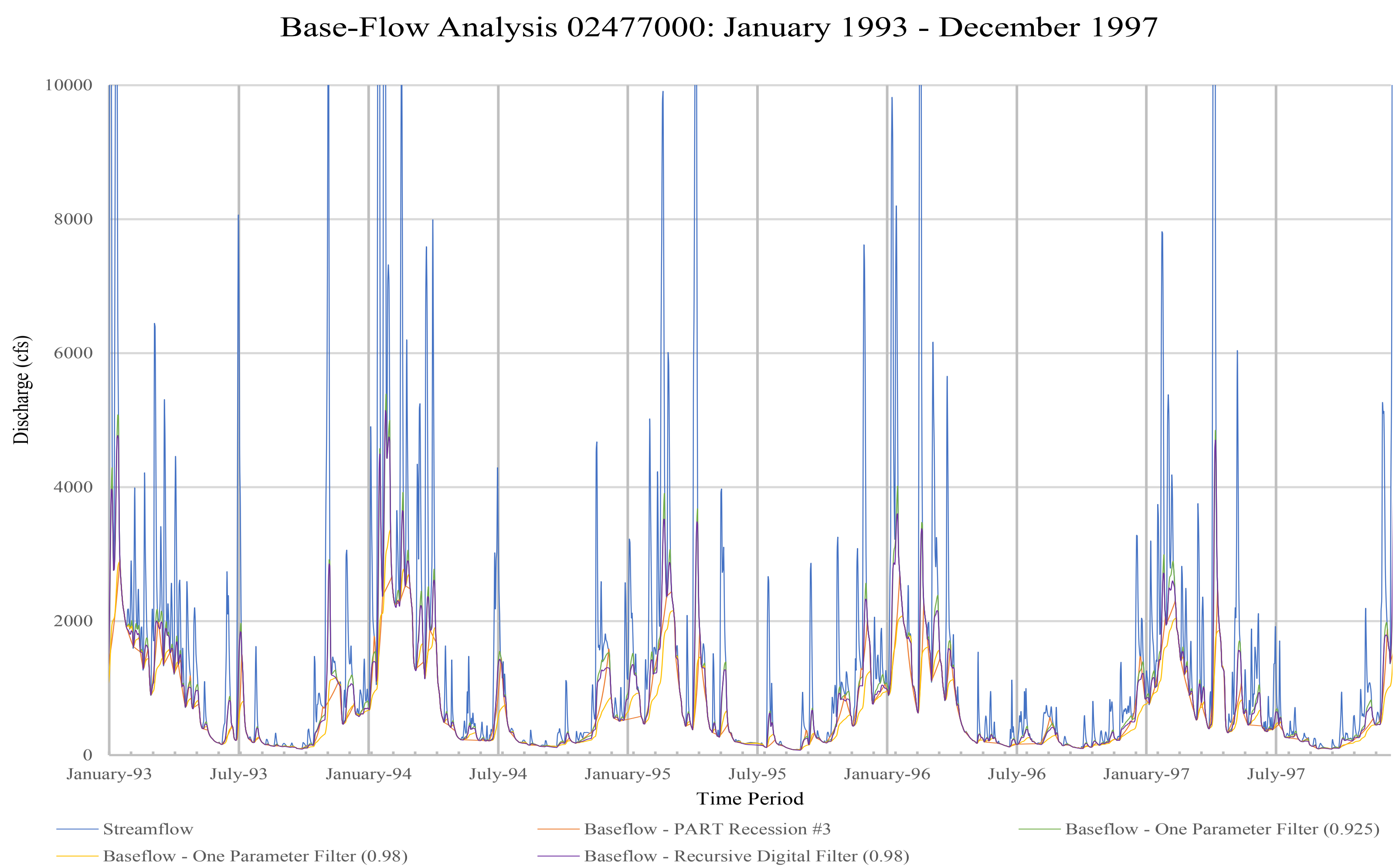

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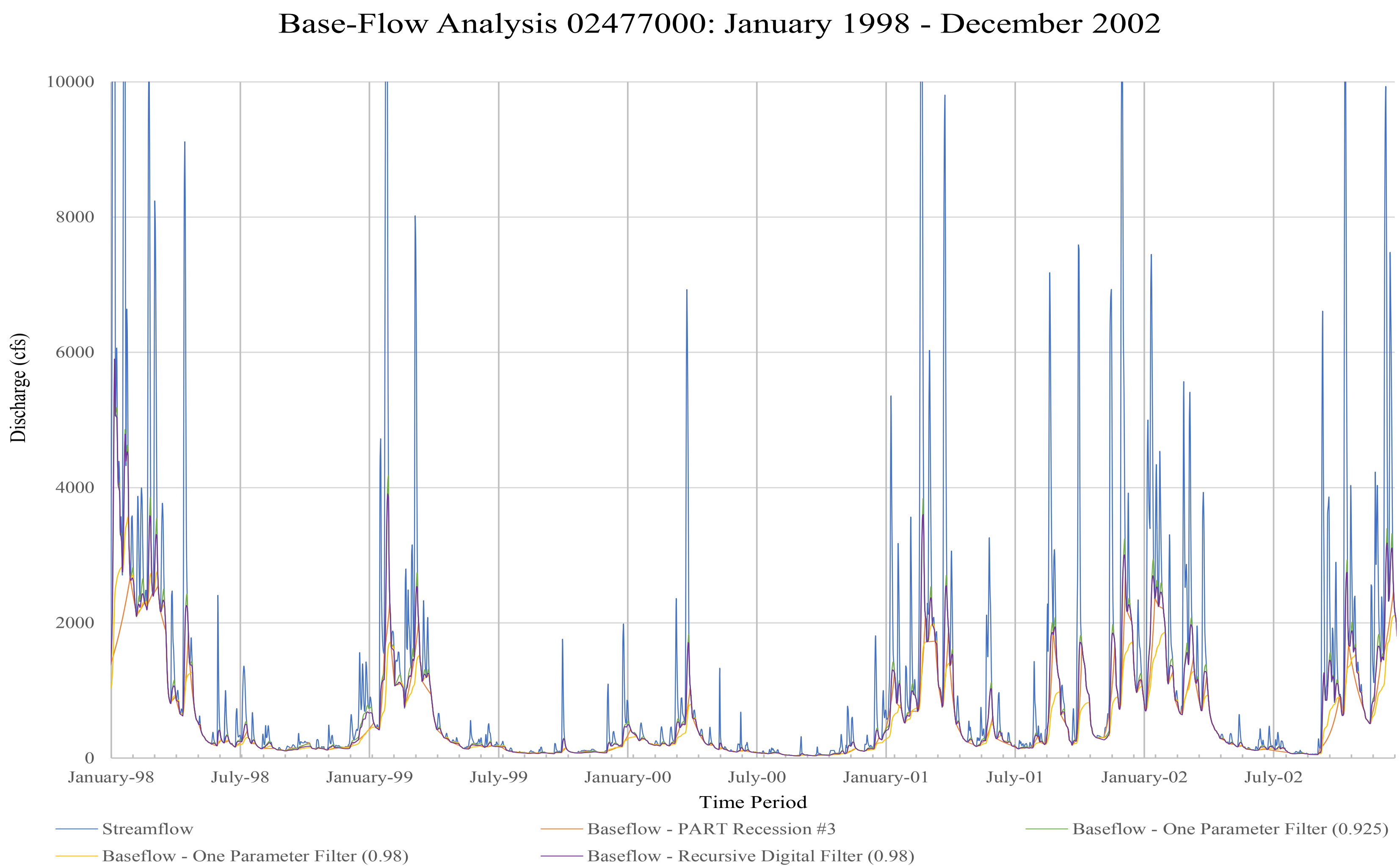

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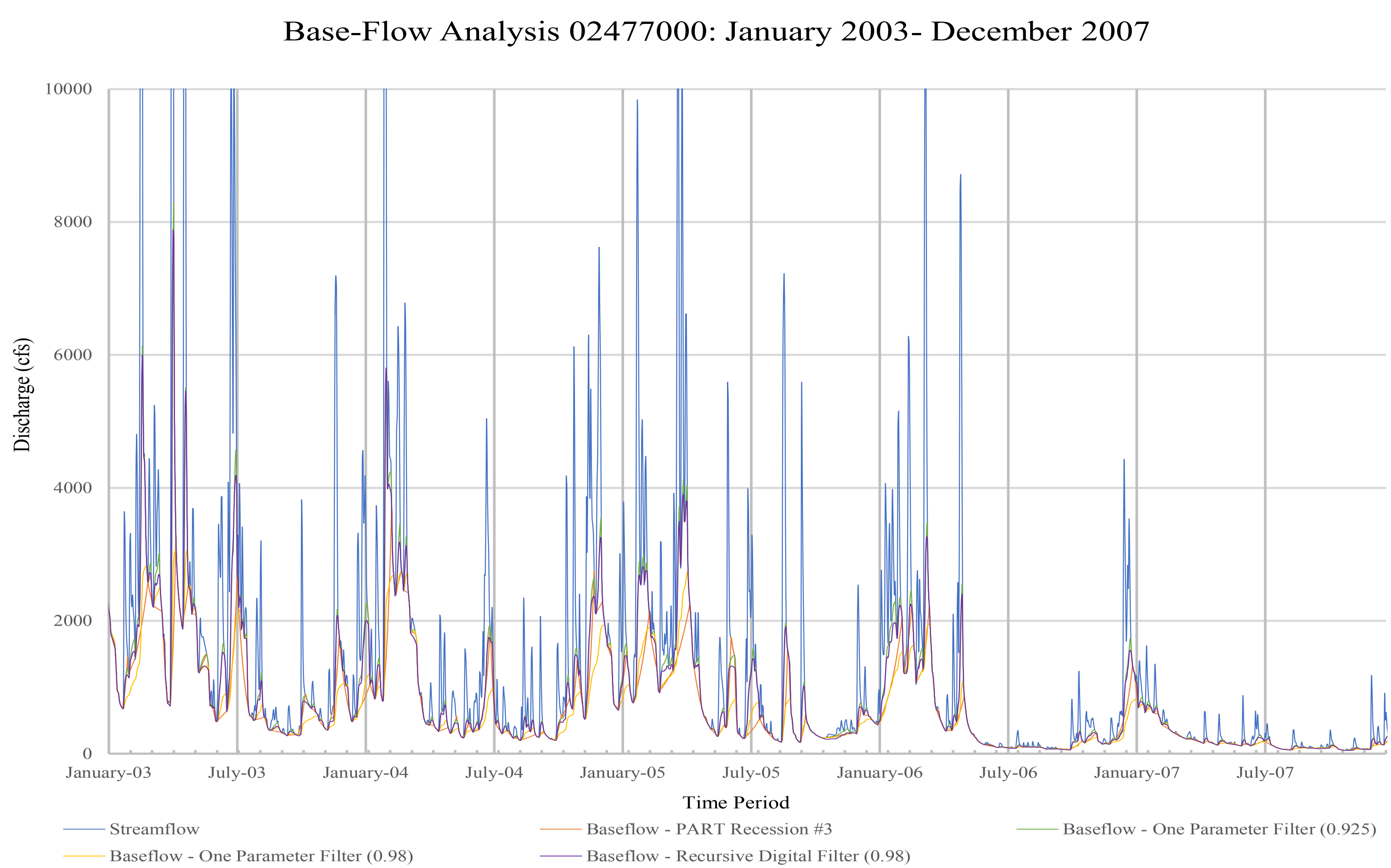

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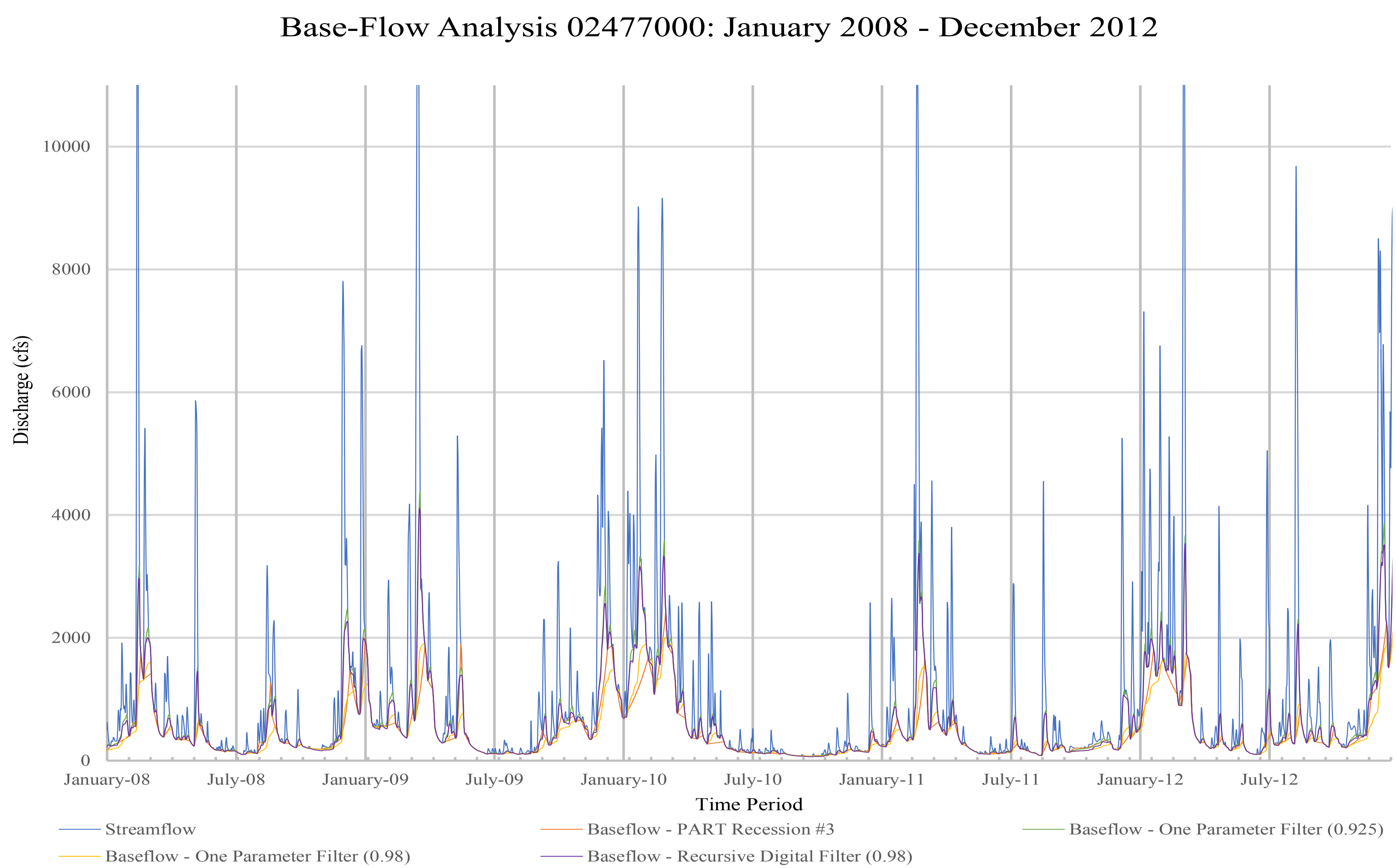

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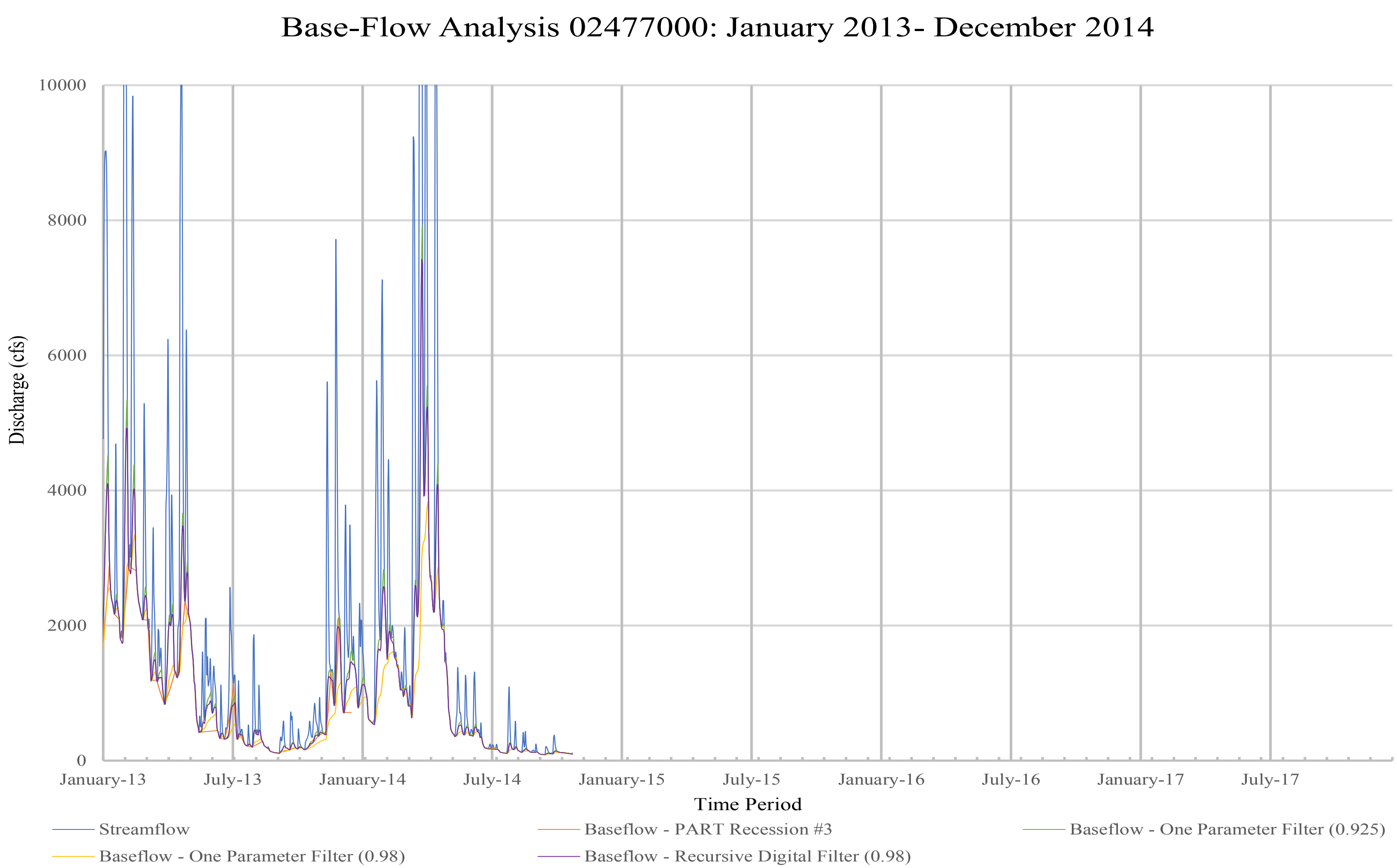

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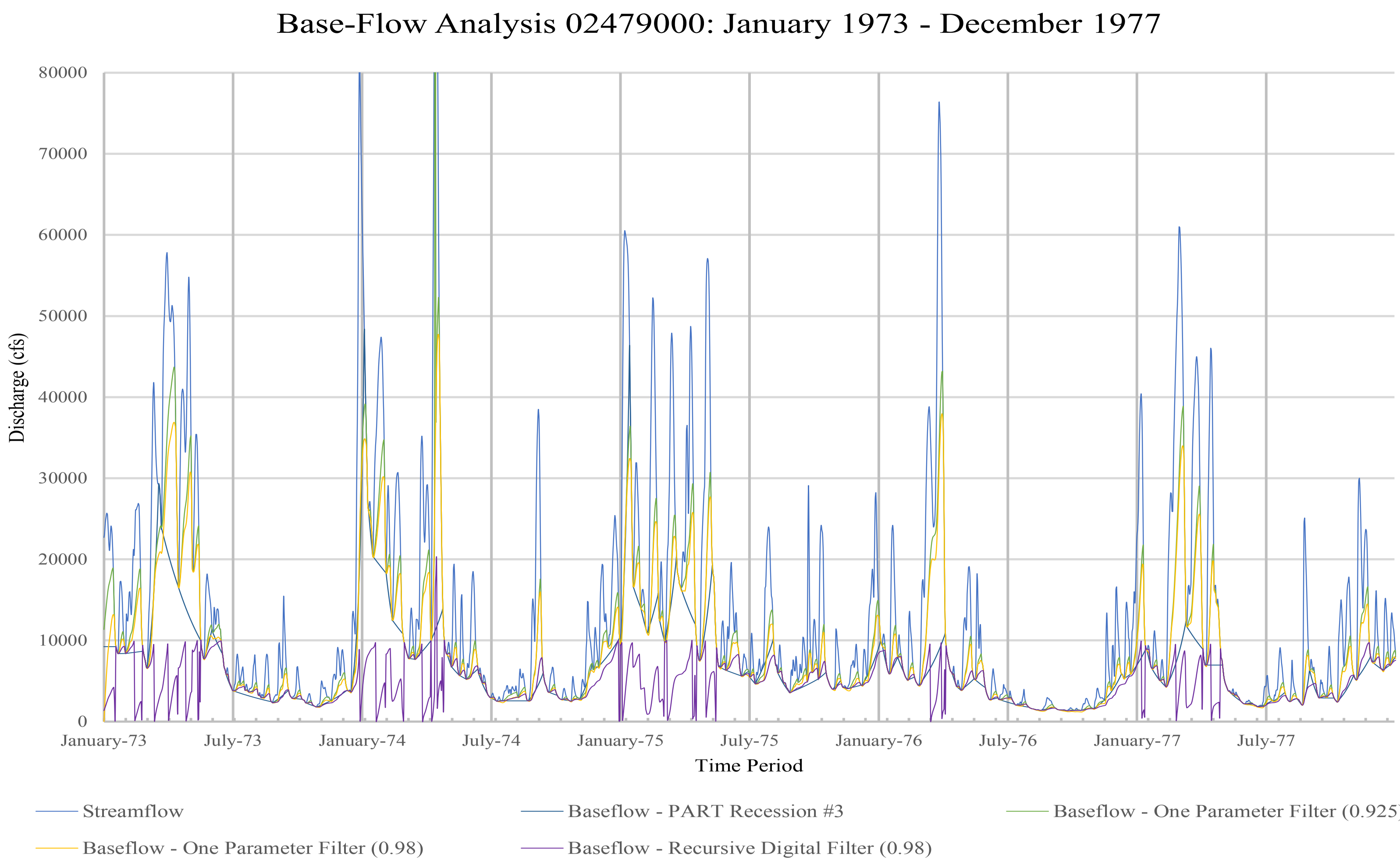
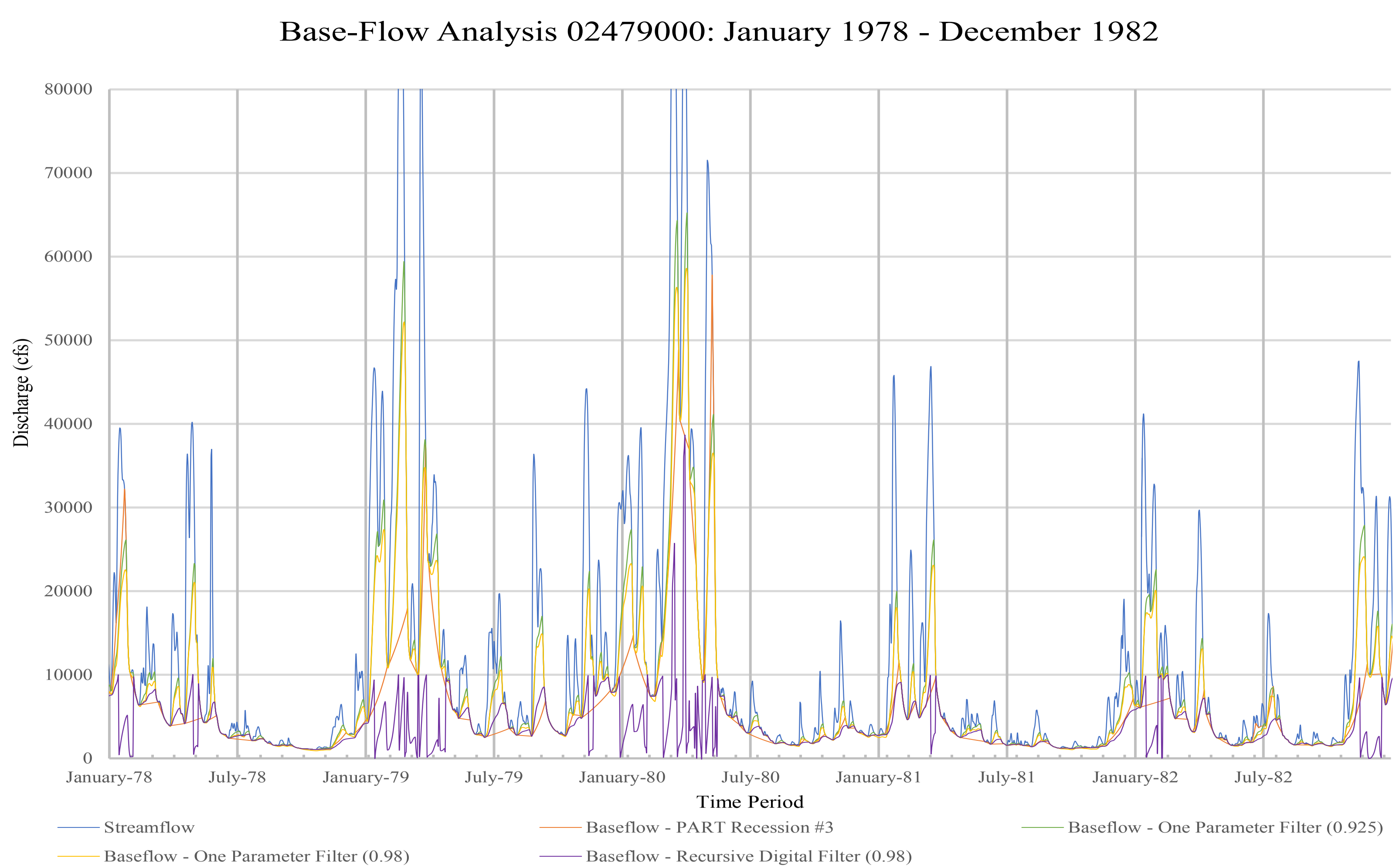


Figure A.19 02479000 January 1973 to December 1977



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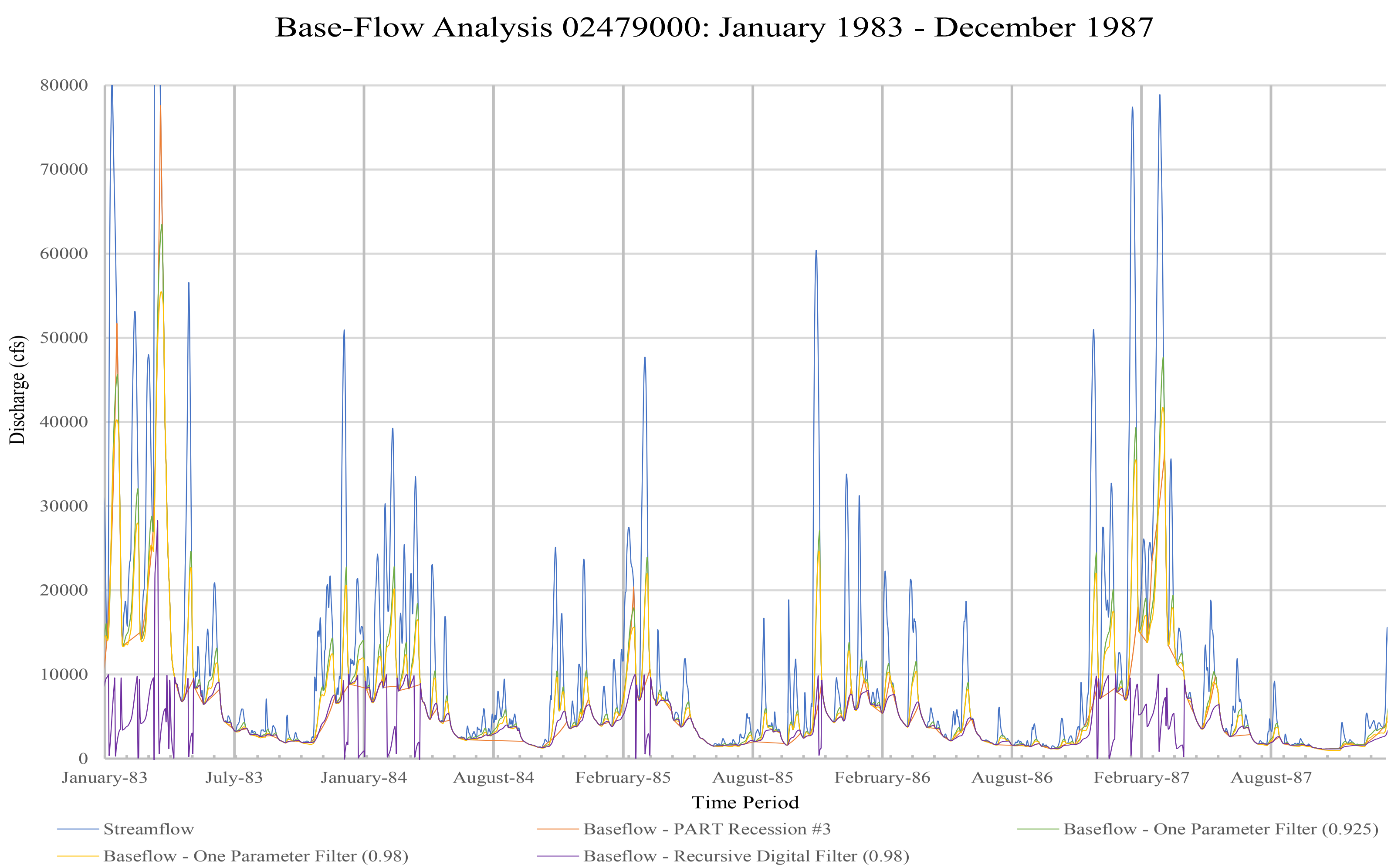

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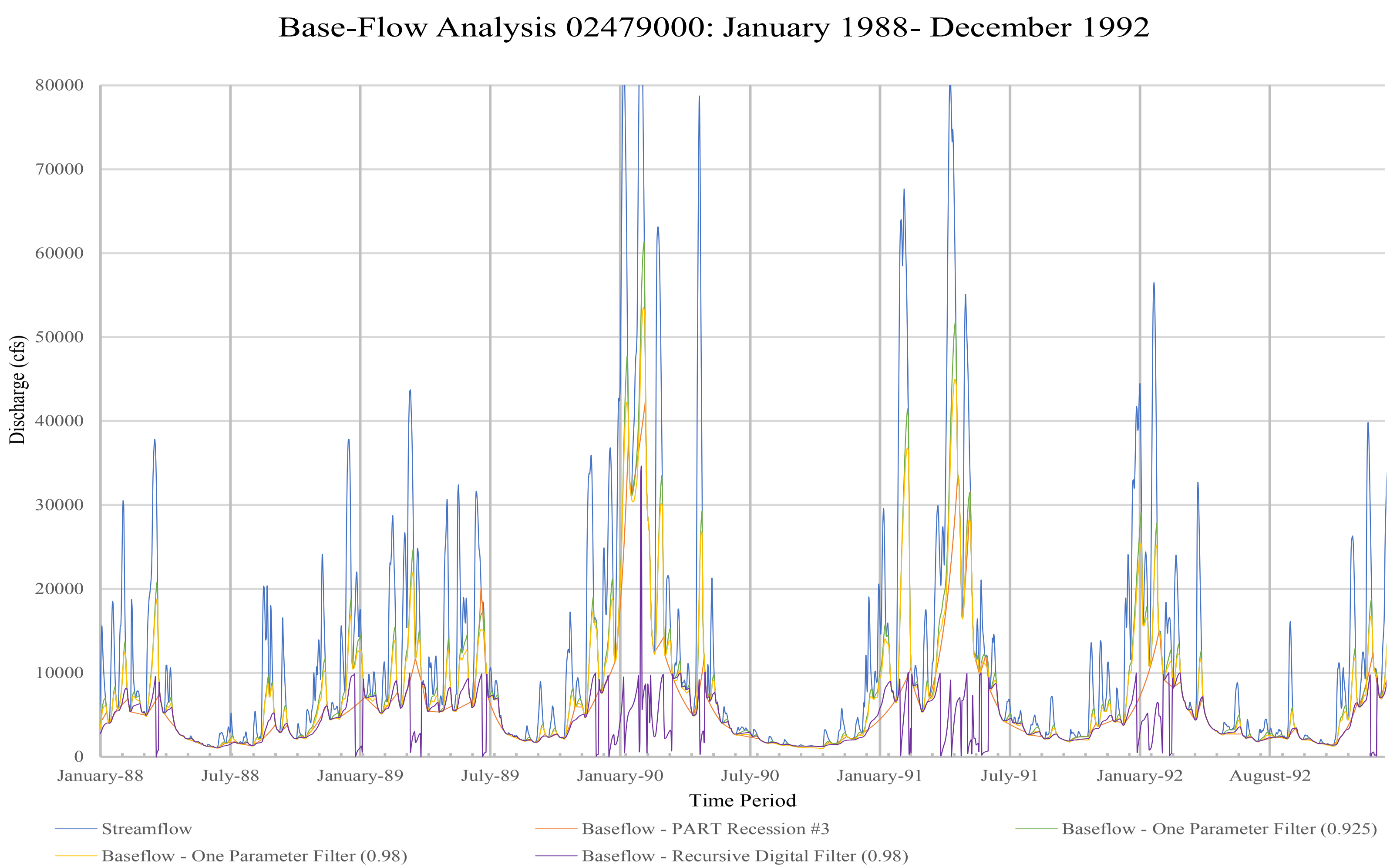

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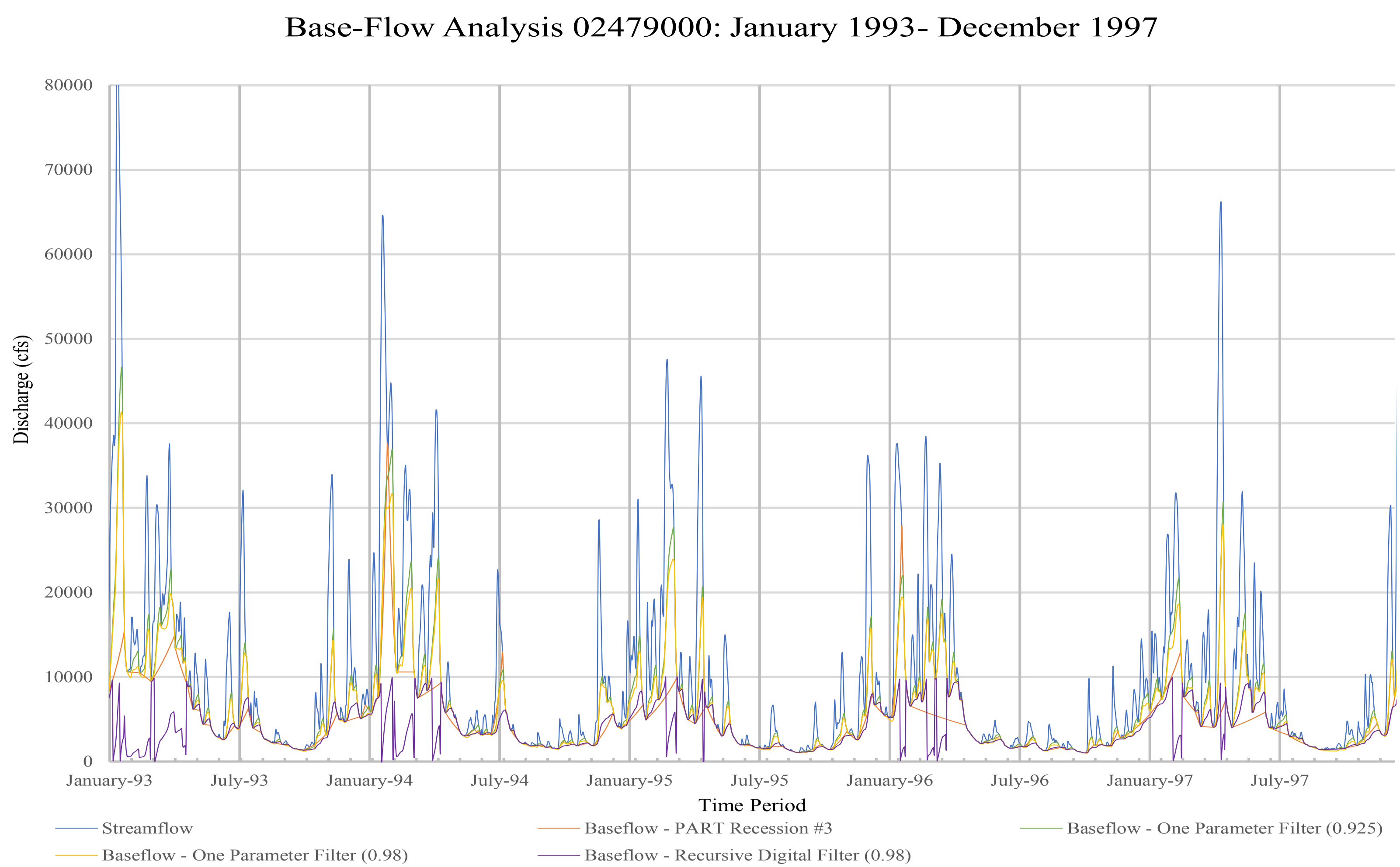

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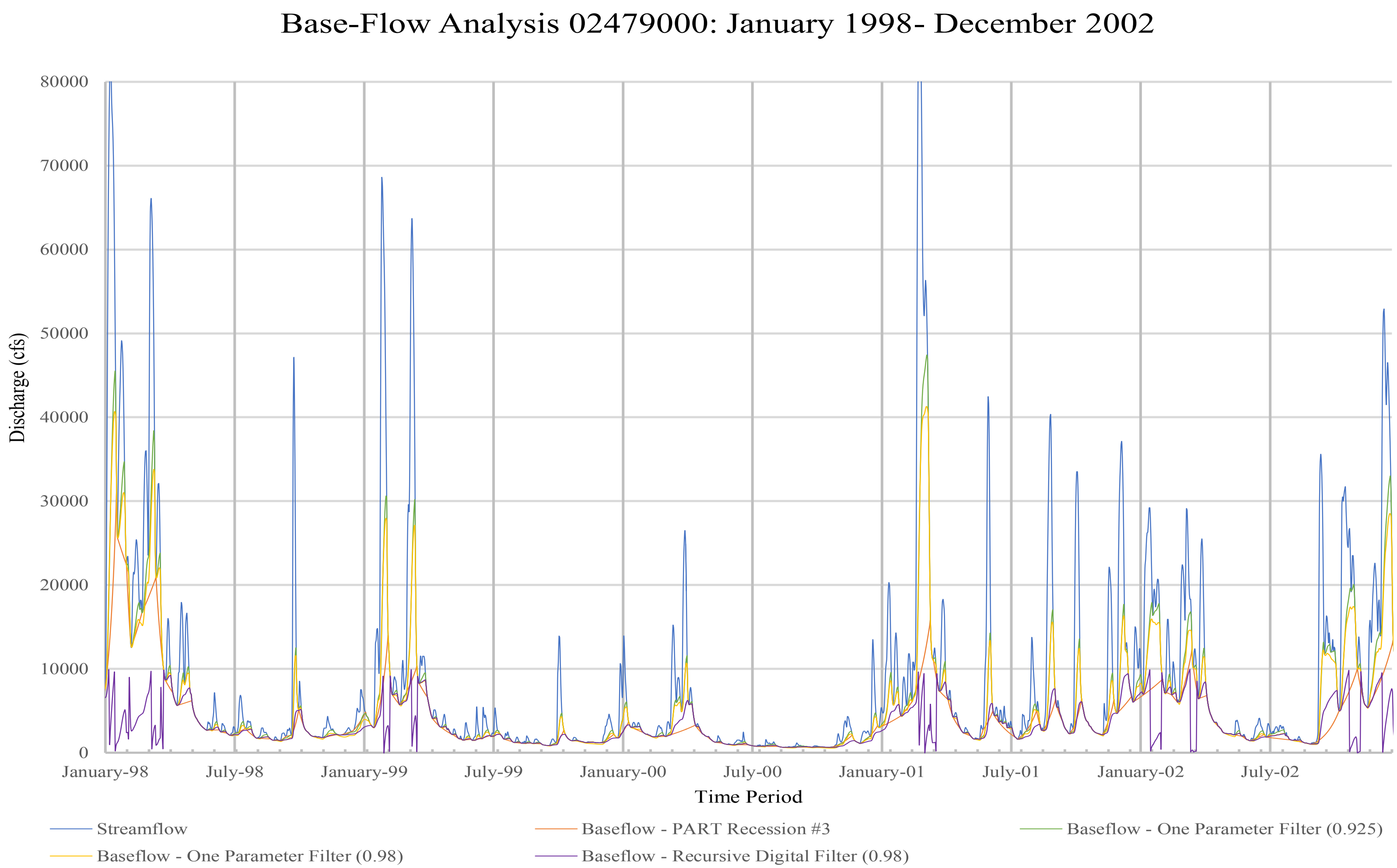

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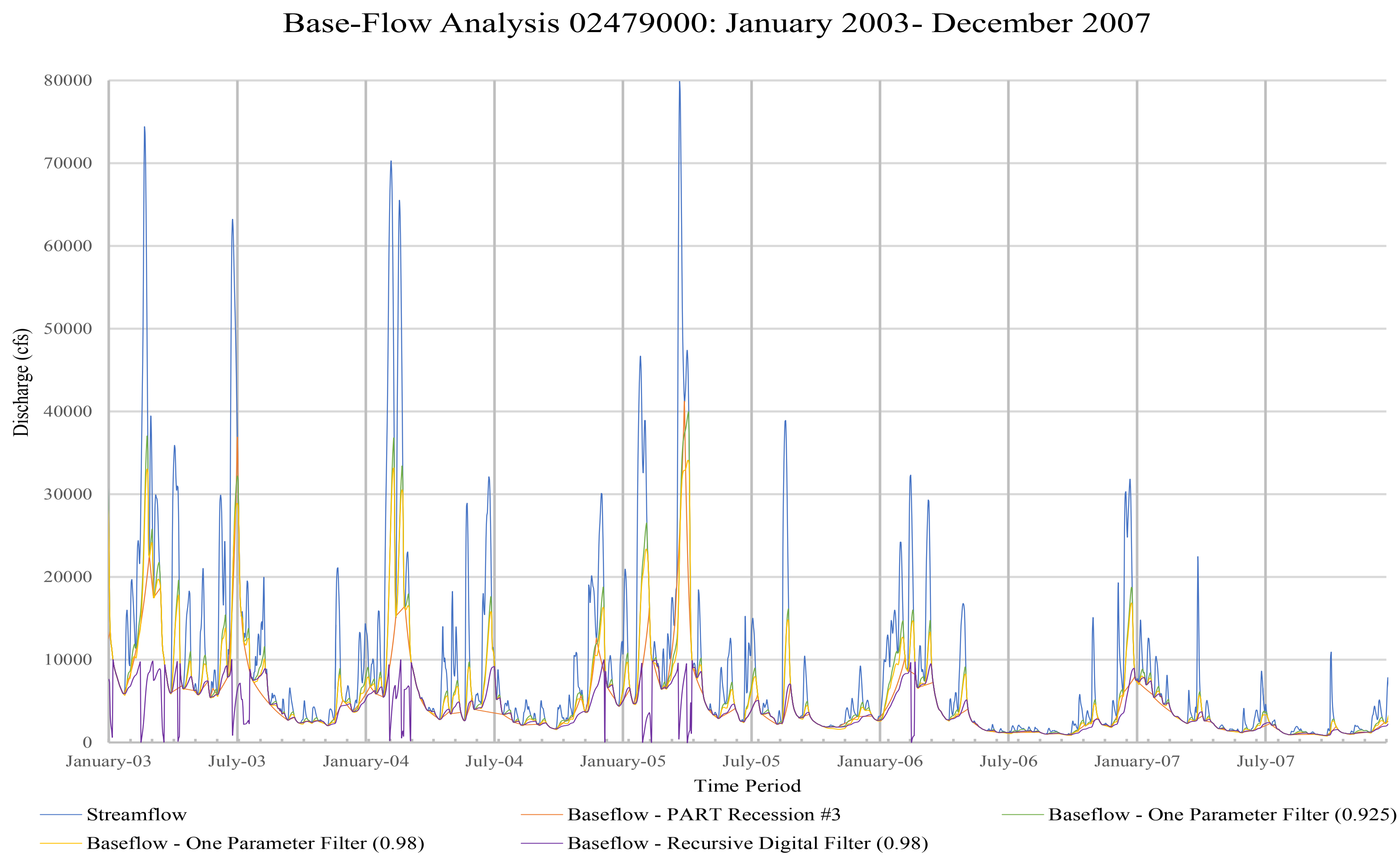

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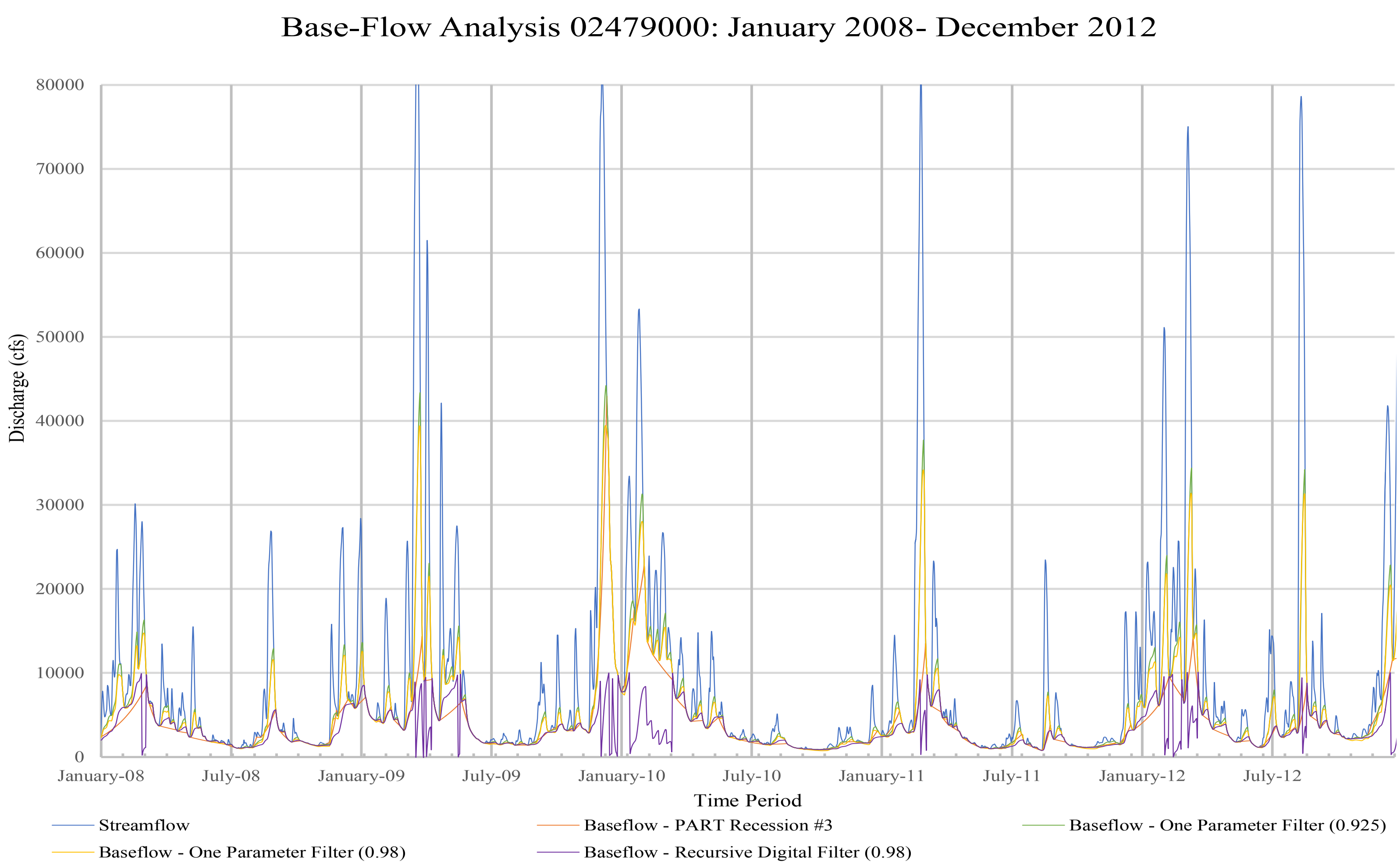

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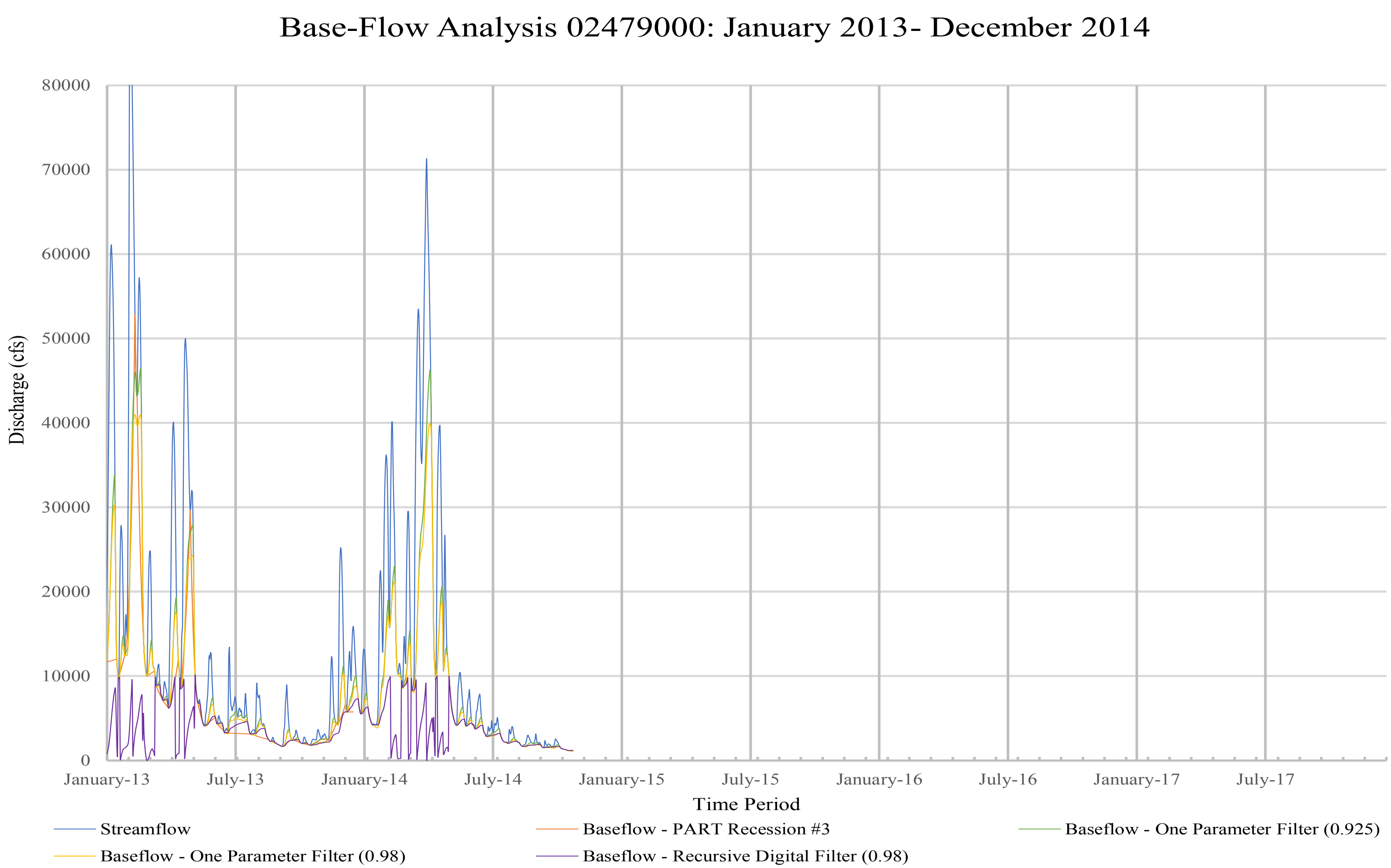

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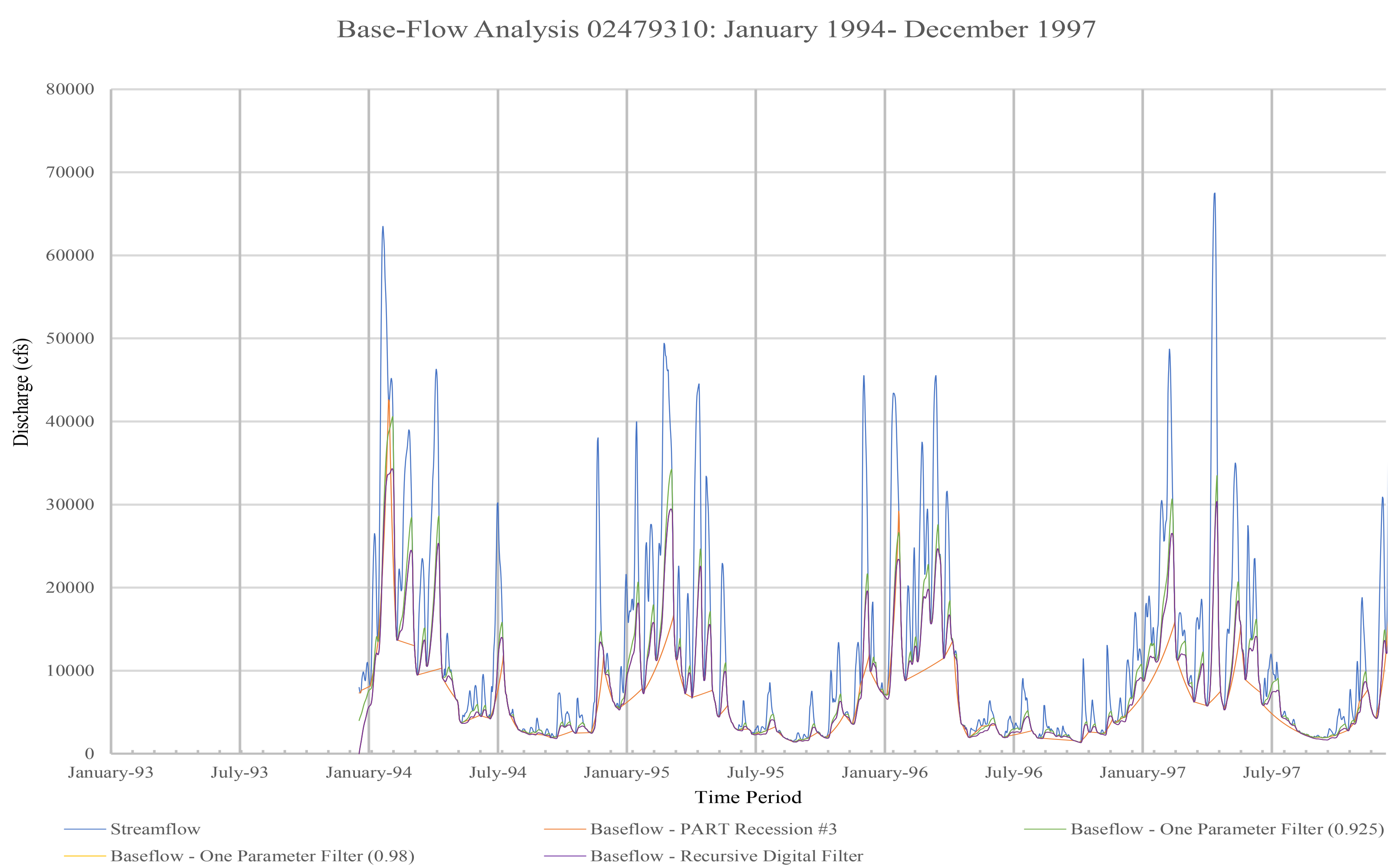

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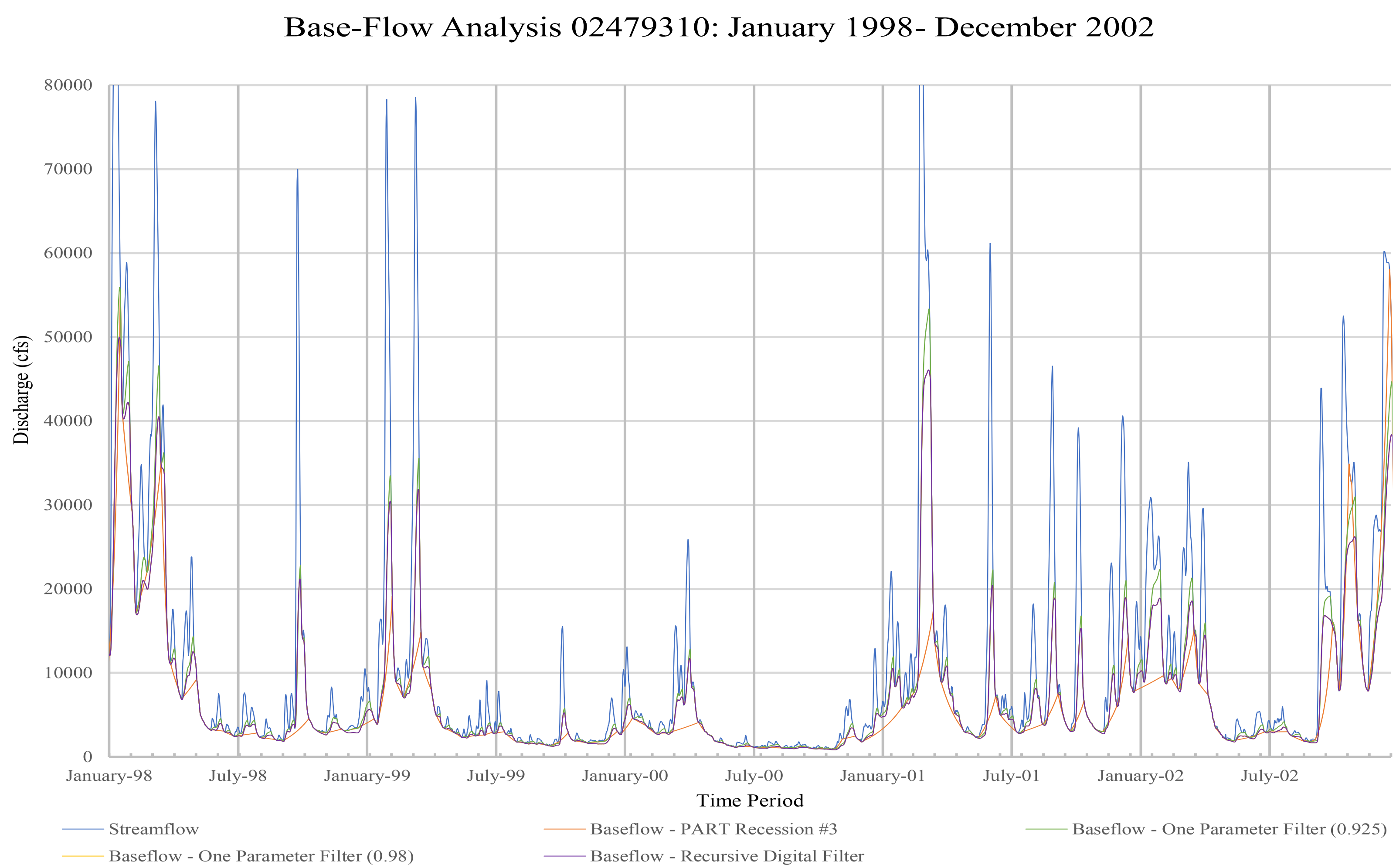

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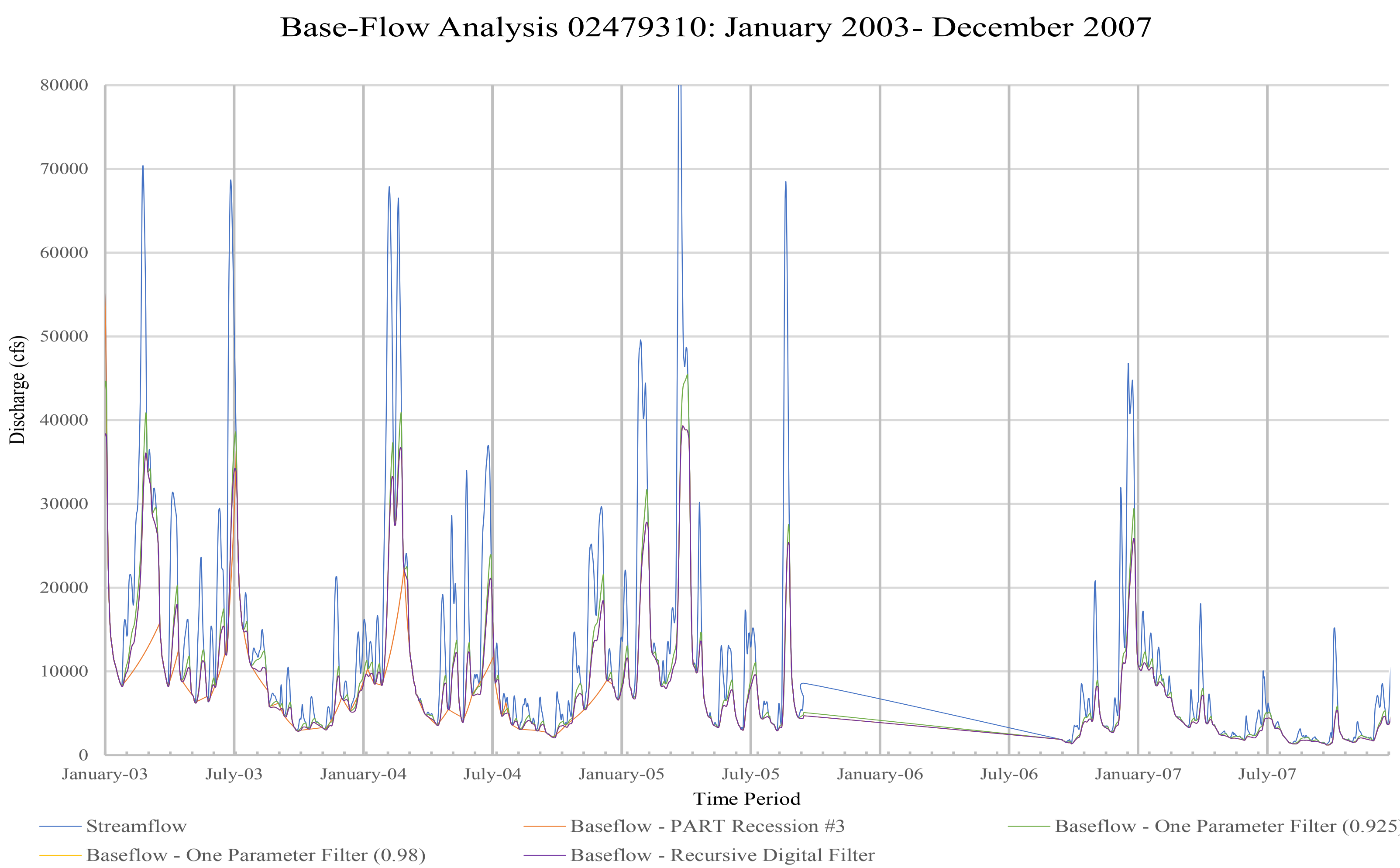

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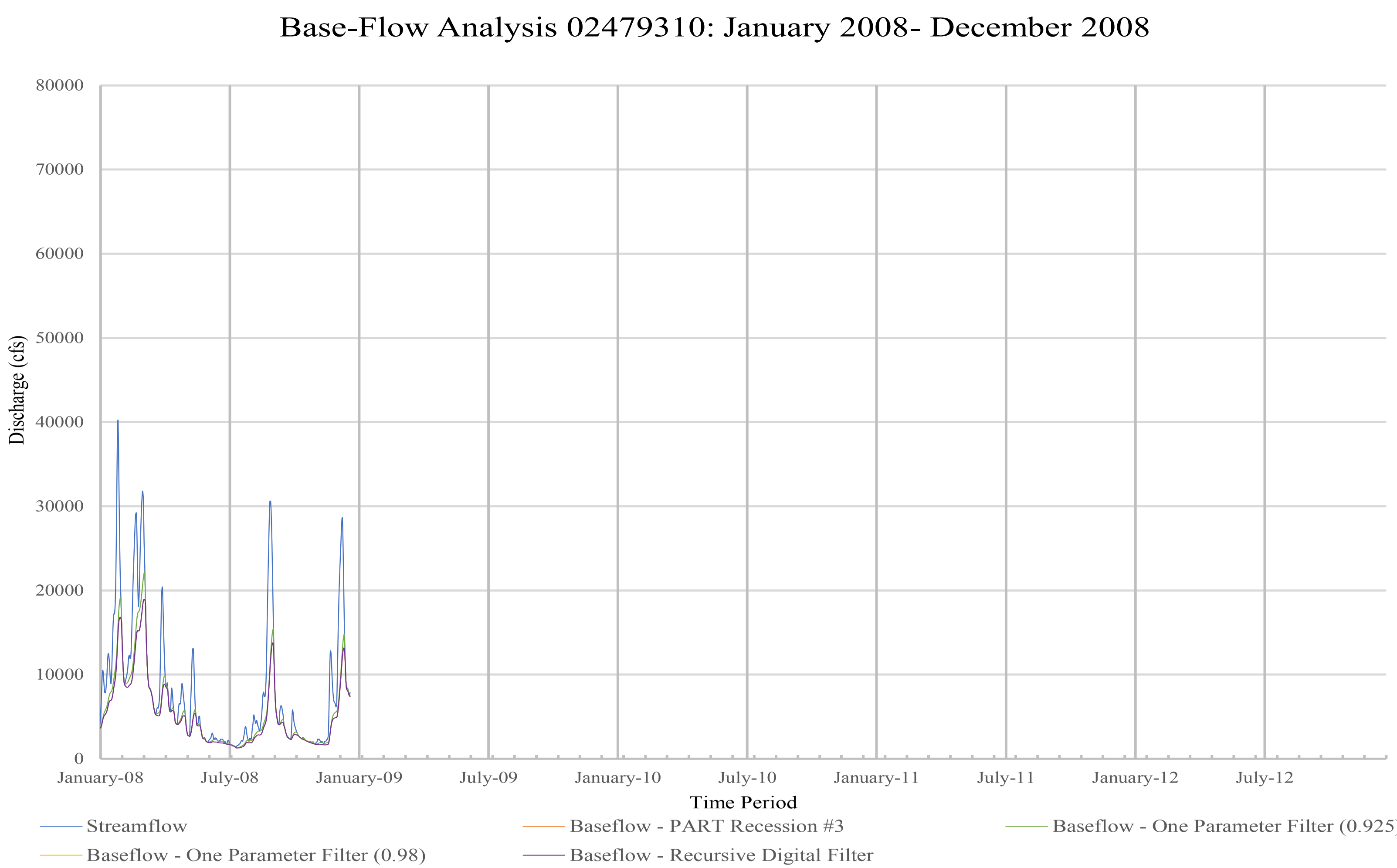

Figure A.31 02479310 January 2008 to December 2008

APPENDIX B

BOREHOLE LOGS

Table B.1 Well No. GC-1 (George County), drilled June 23, 2014

Depth		Soil Strata
From	**To**	**Soil Descriptions and Remarks**
0	2	Sand: Red, med- coarse grain
2	4	Sand: Yellowish-tan fine grain, silty
4	5	Sand: Yellow-tan mottled, clayey at bottom
5	8	Clay: tan-yellow mottled, firm, grey at bottom
8	12	Clay: grey, some orange mottles, firm
12	16	Clay: grey, very dense
16	20	Clay: grey, very dense
20	21	Clay: grey, very dense, some orange mottles
21	24	Clay: blue grey, very hard and dry
24	26	Clay: blue grey, very hard and dry
		Geoprobe refusal

Table B.2 Well No. GC-2 (George County), drilled June 23, 2014

Depth		Soil Strata
From	**To**	**Soil Descriptions and Remarks**
0	1	Silt: brown, with fine sand
1	4	Sand: reddish-brown, silty, med grained, firm
4	8	Sand: reddish-brown, silty, med grained, firm
8	12	Sand: reddish-brown, silty, med grained, firm
12	16	Sand: alternating, red, tan-cream, white, loose, fine grained, (laminated layering every 1/8”)
16	20	Sand: alternating, red, tan-cream, white, loose, fine grained, (laminated layering every 1/8”)
20	24	Sand: white, fine grained (a few pink layers from 22-24’)
24	28	Sand: white, fine grained (a few pink layers from 22-24’)
28	30	Sand: white, fine grained (a few pink layers from 22-24’)
30	32	Sand: red, yellow, orange, white (multicolored every 1/8”), fine grained, wet
32	34	Sand: pink-tan, fine grained, wet
34	35	Sand: yellow
35	36	Sand: tan-pink, some yellow layers
36	41	Sand: yellow-tan-pink, alternating layers, some pink clay at 38’
41	44	Clay: pink and white at 41’, thin tan and yellow alternating
44	46	Clay: tan-yellow, some purple, sandy in places
46	48	Sand: orange and yellow, some clay layered
48	52	Sand: orange and yellow, clayey throughout
52	53	Clay: purple and white
53	56	Sand (maybe silt?): tan-white-pink, silty, clayey Wet from 28 feet to bottom of well

Table B.3 Well No. GC-3 (George County), drilled June 26, 2014

Depth		Soil Strata
From	**To**	**Soil Descriptions and Remarks**
0	1	Grass/ topsoil
1	2	Sand: brown, silty, fine grained, becoming more red at bottom
2	4	Sand: reddish-brown, fine grained, becoming orange-red at bottom
4	8	Sand: light reddish-tan, fine grained
8	11.5	Sand: light reddish-tan, fine grained
11.5	12	Sand: yellowish-grey
12	12.5	Sand: yellowish-grey
12.5	13.5	Clay: purple and yellow mottled, moist, very dense, malleable brown inclusions at bottom
13.5	16	Clay: orange and grey mottled, very firm, malleable, moist
16	19	Clay: yellowish-grey with orange mottles, dense, malleable, less orange at bottom
19	20	Clay: grey, dense, malleable, black specks
20	24	Clay: greyish tan, very firm, malleable, dense, moist
24	26.5	Clay: light tan, malleable, moist
26.5	28	Clay: blue-grey, very dense, firm
28	32	Clay: blue-grey, very dense, firm
		------stuck in barrel/ can't penetrate---- no water/no well-------------------

Table B.4 Well No. GC-4 (George County), drilled June 25, 2014

Depth		Soil Strata
From	**To**	**Soil Descriptions and Remarks**
0	1	Grass/ topsoil
3	4	Sand: brown fine, fine grained
4	8	Clay: grey, mottled with red and yellow, silty, firm
8	10	Silt: tan, red mottles, clayey, some sand
10	12	Sand: yellowish orange, red mottles, very fine grained, moist
12	15	Sand: yellowish orange, red with some grey mottles
15	16	Clay: grey and orange laminated every ¼-1/2" , very dense and sticky
16	20	Clay: blue-grey, very dense and firm
20	22	Sand: tan, few orange mottles, silty, very fine sand
22	22.5	Clay: blue-grey, very dense and firm
22.5	23	Clay: tan with interbedded orange sand and orange clay
23	24	Clay: blue-grey, very dense and firm
24	28	Clay: blue-grey, very dense and firm (~2" of grey silty sand at 23')
28	32	Clay: blue-grey, very dense, firm
		Geoprobe refusal: could not get clay out of barrel; no water

Table B.5 Well No. GC-5 (George County), drilled June 25, 2014

Depth		Soil Strata
From	To	Soil Descriptions and Remarks
0	1	Grass/ topsoil
1	4	Sand: brown to tan, with orange mottles
4	5	Sand: tan with orange mottles
5	7	Sand: tan with few orange and red mottles, moist
7	8	Sand: tan, wet
8	12	Clay: orange with grey mottles, more silty at top, moist
12	15	Clay: orange with grey mottles
15	16	Clay: grey with orange mottles, some intervals of grey
16	20	Clay: blue-grey, very dense hard (top 6”=moist)

Table B.6 Well No. GC-6 (George County), drilled June 25, 2014

Depth		Soil Strata
From	To	Soil Descriptions and Remarks
0	1	Grass/ topsoil
1	4	Silt: orange-brown with red mottles
4	6	Clay: orange with grey mottles, slightly silty
6	8	Clay: grey with orange mottles
8	12	Clay: tan, dense, moist
12	14	Clay: tan, orange mottles (fewer)
14	16	Clay: blue-grey, very dense, hard, sticky
16	20	Clay: blue-grey very dense, stuck in barrel
20	24	No samples---- can’t penetrate with geoprobe

Table B.7 Well No. GC-7 (George County), drilled June 24, 2014

Depth		Soil Strata
From	**To**	**Soil Descriptions and Remarks**
0	1	Grass/top soil
1	4	Sand: red, silty, med grained (loose sand)
4	8	Sand: red, silty, med grained (loose sand)
8	12	Sand: orangeish-red, silty, (very loose sand)
12	16	Sand: orangeish-red, silty, (very loose sand)
16	20	Sand: orangeish-red, silty, (very loose sand)
20	24	Sand: red, yellowish-tan (very loose sand)
24	28	Sand: top 6" is red, then yellowish-tan, pinkish at bottom, loose sand at top to very loose at bottom
28	32	Sand: red, except 3" section (at 31') golden brown sand
32	34	Sand: red, except 2" of red clay at 32'
34	36	Sand: greyish-cream, mottled with yellowish-orange sand, moist
36	38	Sand: greyish-cream, mottled with yellowish-orange slightly silty, wet
38	40	Sand: red alternating with greyish-cream and yellow-orange, slightly silty, wet
40	44	Sand: red alternating with greyish-cream and yellow-orange, slightly silty, wet
44	48	Sand: red alternating with greyish-cream and yellow-orange, slightly silty, wet
48	52	Sand: red alternating with greyish-cream and yellow-orange, slightly silty, wet
52	56	Sand: red alternating with greyish-cream and yellow-orange, slightly silty, wet
		Set well at 56ft Water from 32 feet to bottom of well

Table B.8 Well No. GC-8 (George County), drilled June 24,2014

Depth		Soil Strata
From	**To**	**Soil Descriptions and Remarks**
0	1	Grass/ topsoil
1	4	Sand: tan, fine grained (very loose sand)
4	6	Sand: tan, fine grained (very loose sand)
6	8	Sand: orange to tan, (very loose), wet
8	12	Sand: orange to tan, (some gravel at 11'), wet
12	16	Sand: tan, some orange, sandy silt interval at ~ 13', wet
16	20	Sample consisted of heaving sand from below
20	24	Sand: tan
24	28	Set well at 28ft; screen at 20ft

Table B.9 Well No. GC-9 (George County), drilled June 24, 2014

Depth		Soil Strata
From	To	Soil Descriptions and Remarks
0	1	Grass/ topsoil
1	4	Sand: red, silty, firm
4	8	Sand: red, silty, firm
8	12	Sand: red, silty, firm
12	15	Sand: red, silty, firm, finer grained, some tan inclusions
15	16	Sand: light tan, some red sand, very loose
16	17	Sand: red with brown and tan laminations/layers, loose
17	20	Sand: light tan, some red sand at top
20	21	Sand: light tan, very loose sand
21	24	Sand: mostly red, some tan, pink, purple, very loose sand
24	28	Sand: alternating red and tan (~1/4" layers), very loose
28	32	Sand: alternating red and tan (1"-2" layers near bottom)
32	34	Sand: tan and red with very coarse grained, mixed in some pebbles
34	36	Sand: red and tan, med- fine grained
36	40	Sand: light tan, very fine, loose sand
40	44	Sand: light tan, very fine, loose sand
44	46	Sand: light tan, very fine, loose sand, some (3") of coarse sand at top
46	48	Sand: red with tan and yellow mottles, moist
48	52	Sand: tan with red and pink mottles, fine grained, loose sand
52	53	Sand: pink, slight mottles of yellow
53	54	Clay: pinkish-tan (flesh colored), silty, mottled with purple and rust at 54'
54	56	Sand: yellowish-tan to 55', then reddish-tan to 56', mottles
56	58	Sand: pink with tan, red, and yellow mottles, fine grained, loose sand
58	60	Sand: yellowish-tan, some red mottles, fine grained, loose sand, moist
60	61	Sand: yellowish-tan, fine grained
61	62.5	Sand: tan with red and yellow mottles
62.5	63	Clay: pink and purple mottled, silty
63	64	Sand: purple with tan and yellowish-orange mottles in lower part, moist
64	68	Sand: pink, purple and yellowish-orange mottles in lower part, wet
		-------------------Heaving sand---------------------
		Pushed and set well at 79ft
		Water from 40 feet to bottom of well

Table B.10 Well No. GC-10 (George County), drilled June 25, 2014

Depth		Soil Strata
From	To	Soil Descriptions and Remarks
0	2	Grass/ topsoil
2	3.5	Clay: brown, silty
3.5	4	Sand: grey with orange mottles
4	8	Sand: red, few orange and yellow mottles, wet
8	12	Sand: red, few orange and yellow mottles, wet
12	16	No sample ---- heaving sand-------
		Pushed well to 37ft; 20ft screen
		Water from 6 feet to bottom of well

Table B.11 Well No. GC-11 (George County), drilled June 25, 2014

Depth		Soil Strata
From	To	Soil Descriptions and Remarks
0	1	Grass/ topsoil
1	3	Sand: brown with grey mottles, silty
3	4	Clay: grey with orange- red mottles, silty
4	8	Clay: grey with orange-red mottles, no silt, more red at top, orange at bottom
8	12	Clay: grey with orange mottles
12	16	Clay: grey with orange mottles- fewer orange mottles
16	17	Sand: grey
17	17.5	Clay: grey, only ~4"
17.5	20	Sand: orange, with grey mottles to 18.5', 1" of grey clay at 18.6'
20	23	Sand: orange, with grey mottles
23	24	Sand: grey with some orange sand, black specks at bottom, moist
24	28	Sand: orange to grey mottles, some black specks, wet
28	31	Sand: tan with pink and yellow mottles, some pebbles with black specks, wet
31	32	Sand: pinkish tan (flesh colored) with black specks, wet
32	36	Sand: pinkish tan (flesh colored) with black specks, wet
36	40	Sand: greyish tan, with some orange mottles (more orange at 38'-38.5')
		--------------Heaving wet sand-------------------
		Pushed and set well to 46ft; 20ft screen
		Water from 20 feet to bottom

Table B.12 Well No. GC-12 (Jackson County), drilled June 27, 2014

Depth		Soil Strata
From	**To**	**Soil Descriptions and Remarks**
0	1	Grass/ topsoil
1	4	Sand: red, med-coarse grained, loose
4	8	Sand: red, fine grained
8	9	Sand: red, fine grained
9	12	Sand: orangish-red, fine grained, several layers of tan sand at bottom
12	14	Sand: red, coarsing downward, some pebbles/ gravel at bottom
14	15	Sand: 4”of red, 3” of tan and brown, mottled, with gravel, 4” of greyish brown with gravel, 1” of red with gravel above clay
15	16	Clay: yellow-orange and grey, mottled, stiff, malleable
16	18	Clay: grey at top, yellow-orange and purple mottled
18	20	Clay: yellow-orange, some greyish purple at 19’, purple and yellow-orange mottled
20	24	Clay: grey more yellowish-orange within top foot, dense
24	28	Clay: grey, very dense, firm, malleable
28	31.5	Clay: grey, very dense, firm, malleable
31.5	32	Sand: grey (only ~4” at bottom of tube)
32	34	Clay: grey, slight orange and red, malleable, sandy at top
34	36	Clay: grey, no mottles, very dense, firm
36	38	Clay: grey, very dense, firm, with orange and purple mottles at bottom
38	39	Clay: grey, yellow, orange and red mottled, very dense, firm
39	40	Clay: grey, very dense and firm
40	42	Clay: grey, slight yellow-orange mottles very dense and firm
42	43.5	Clay: grey and yellow-orange mottled, very dense and firm
43.5	44	Clay: bright orange
44	45	Sand: orange sand with 2” of reddish-brown gravel at top and sand at bottom
45	46	Sand: yellow-orange at top, tan and grey with orange laminated at bottom
46	48	Sand: grey, tan and orange laminated (layers are ~4”)
48	52	Sand: yellow, orange and tan alternating layers that vary from ~1/2” to 2”

Table B.13 Well No. GC-13 (Jackson County), drilled June 26, 2014

Depth		**Soil Strata**
From	**To**	**Soil Descriptions and Remarks**
0	1	Grass/ topsoil
1	4	Sand: brown, silty, loose
4	8	Sand: reddish-brow, becoming reddish tan at 8’, loose
8	11.5	Sand: red, some fine gravel, fining downward
11.5	12	Sand: tan, loose, malleable with silightly grey sand
12	14	Sand: white and red laminated
14	16	Sand: red, some pebbly gravel, loose
16	19	Sand: white and red laminated
19	20	Sand: red coarse grained
20	24	Sand: alternating red, white, grey, yellow, fine grained, wet
24	28	Sand: tan, flesh colored, pink, purple, orange alternating, some mottles
28	30	Sand: orange, loose, some clay at 29.5’
30	32	Clay: orangish-yellow, moist, very sticky, some fine grey sand at 30’
32	34	Clay: orangish-yellow
34	36	Clay: grey with black inclusions, more tan at 36’
36	40	Clay: greyish-tan, very dense, blood red inclusions
40	42	Clay: greyish-tan, very dense, no red
42	44	Clay: grey, very dense, malleable
44	45.5	Clay: grey, very dense, malleable
45.5	46	Sand: orange and grey mottled, some clay at 45.5’

APPENDIX C

GRAIN SIZE ANALYSIS

Table C.1 GC-1Sieve weight retained

GC-1								
Interval	**Initial Weight**	**Sieves**						
		10	18	35	60	120	230	B
(ft)	(g)	(g)	(g)	(g)	(g)	(g)	(g)	(g)
0-2	430.3379	10.4530	7.8649	88.7022	178.4536	79.5259	33.7574	32.4880
2-4	451.6600	4.6439	1.4834	45.5988	199.5482	147.5355	32.3024	22.0929
4-5	254.5625	7.7670	5.2343	19.5465	83.5097	60.6065	38.2405	40.5230
5-8	CLAY							
8-12	CLAY							
12-16	CLAY							
16-20	CLAY							
20-21	CLAY							
21-24	CLAY							
24-26	CLAY							

Table C.2 GC-2 Sieve weight retained

GC-2								
Interval	**Initial Weight**	**Sieves**						
		10	18	35	60	120	230	B
(ft)	(g)	(g)	(g)	(g)	(g)	(g)	(g)	(g)
0-1	190.9199	0.1160	0.4592	14.4870	85.4891	47.2353	19.0143	24.8980
1-4	737.5086	0.1058	4.3003	63.9955	359.2060	194.5158	67.8280	49.0043
4-8	566.9447	0.2480	4.5040	79.6073	368.5944	198.9554	72.5805	48.9635
8-12	968.0556	0.3241	8.3157	97.3573	489.1821	265.1582	70.3669	38.3695
12-16	633.8103	0.2777	6.1251	63.5159	288.6167	221.9225	41.4828	8.4870
16-20	718.3520	0.3388	2.2970	35.7510	348.4263	275.0876	42.3434	7.4622
20-24	554.6504	0.0000	0.2383	7.9545	293.1413	216.9949	28.2660	6.6708
24-28	672.1685	2.0537	7.1502	53.0660	333.2072	214.3132	47.9409	11.8238
28-30	444.9476	0.0000	0.0701	3.8117	68.6621	267.2038	83.8619	20.2053
30-32	372.4440	0.0000	0.0590	2.8990	109.1756	204.4281	46.2878	7.6497
32-34	374.1513	0.0000	0.1397	6.3444	233.4295	115.3970	10.6809	5.9693
34-35	CLAY							
35-36	CLAY							
36-41	539.8657	0.0000	0.0513	2.8465	220.4548	236.8376	42.2323	34.5606
41-44	CLAY							
44-46	CLAY							
46-48	CLAY							
48-52	CLAY							
52-53	CLAY							
53-56	SILT+CLAY							

Table C.3 GC-3 Sieve weight retained

GC-3								
Interval	**Initial Weight**	**Sieves**						
		10	18	35	60	120	230	B
(ft)	(g)	(g)	(g)	(g)	(g)	(g)	(g)	(g)
1-2	146.2335	0.0201	2.4155	27.0410	62.6904	32.4661	7.7471	6.6310
2-4	250.8605	0.2463	2.5050	42.0400	124.4198	58.2884	11.8903	9.2206
4-8	240.7126	1.2741	3.9848	34.0166	105.5513	71.8510	14.4171	8.1464
8-11.5	325.0549	0.7824	3.7771	35.6945	220.5827	49.4519	8.6165	5.5866
11.5-12	126.7073	0.0932	0.2613	7.2109	76.3684	38.3606	2.7680	0.8835
12-12.5	214.3895	0.0000	0.4281	11.7783	116.2341	76.8515	5.8639	1.4733
12.5-13.5	CLAY							
13.5-16	CLAY							
16-19	CLAY							
19-20	CLAY							
20-24	CLAY							
24-26.5	CLAY							
26.5-28	CLAY							
28-32	CLAY							

Table C.4 GC-4 Sieve weight retained

GC-4								
Interval	Initial Weight	Sieves						
		10	18	35	60	120	230	B
(ft)	(g)	(g)	(g)	(g)	(g)	(g)	(g)	(g)
3-4	273.3233	2.6546	1.1073	4.9530	47.5774	107.3870	60.5449	49.6749
4-8	CLAY							
8-10	SILT							
10-12	227.7699	0.0000	0.0335	0.1665	22.7866	174.9392	23.8233	6.0023
12-15	257.4994	0.1436	0.2436	0.4078	40.2637	177.3404	29.4796	91.9000
15-16	CLAY							
16-20	CLAY							
20-22	CLAY							
22-22.5	CLAY							
22.5-23	CLAY							
23-24	CLAY							
24-28	CLAY							
28-32	CLAY							

Table C.5 GC-5 Sieve weight retained

GC-5								
Interval	Initial Weight	Sieves						
		10	18	35	60	120	230	B
(ft)	(g)	(g)	(g)	(g)	(g)	(g)	(g)	(g)
1-4	192.4724	0.1252	1.1092	7.7040	72.5212	78.8247	18.4291	13.0000
4-5	100.9194	0.0000	0.0785	0.6884	29.1522	52.0814	12.6383	6.2779
5-7	268.6236	0.1245	1.3509	12.4020	130.5060	103.6140	16.3170	3.3150
7-8	165.6632	0.1239	1.6724	35.1628	98.1317	25.7959	3.7191	1.0778

Table C.6 GC-7 Sieve weight retained

GC-7								
Interval	**Initial Weight**	**Sieves**						
		10	18	35	60	120	230	B
(ft)	(g)	(g)	(g)	(g)	(g)	(g)	(g)	(g)
1-4	261.9746	1.5325	15.1076	68.4550	111.8432	41.8141	15.0940	9.6166
4-8	358.2673	3.1167	11.4008	70.5765	166.7861	69.1095	23.4236	9.4477
8-12	293.4243	1.8245	10.7759	70.5380	166.2378	32.7119	9.4477	2.3390
12-16	423.4333	13.8198	30.1792	72.5580	168.8639	111.4596	23.7996	3.4475
16-20	334.6295	0.0000	0.0683	0.2996	218.2060	95.7110	18.2427	2.5433
20-24	299.6535	0.0000	0.0939	0.1787	133.1890	134.5285	25.7214	6.6853
24-28	442.4084	1.8194	3.0769	16.1511	279.5346	116.7100	21.7014	4.3978
28-32	343.2388	0.0801	0.3527	1.7625	225.8335	104.2400	9.4684	1.8418
32-34	129.6828	4.7576	13.7671	55.3464	9.4609	55.3464	9.4609	6.5038
34-36	225.0953	0.0000	0.0019	0.0435	61.6188	138.6941	13.5319	10.5066
36-38	212.7244	0.2683	0.1845	0.1080	45.9445	139.4332	14.4895	10.4475
38-40	280.6493	0.0000	0.0091	0.0608	92.1780	159.5991	18.4290	9.8071
40-44	275.1396	0.0000	0.0577	0.1717	100.2452	142.5485	21.7417	9.2336
44-48	253.9840	0.0000	0.0043	0.0770	54.7352	169.0536	18.2707	11.8394
48-52	453.2450	0.0512	0.3131	0.4651	142.0752	262.8735	31.3774	14.7923

Table C.7 GC-8 Sieve weight retained

GC-8								
Interval	Initial Weight	Sieves						
		10	18	35	60	120	230	B
(ft)	(g)	(g)	(g)	(g)	(g)	(g)	(g)	(g)
1-4	304.6229	19.8652	14.6598	48.2115	127.1480	52.9642	21.8834	19.2386
4-6	109.0735	0.1846	1.8056	22.2700	64.7475	14.2530	1.2538	0.4632
6-8	204.9164	0.9843	5.2963	3.3332	98.4113	50.5631	11.1785	4.5403
8-12	270.0692	12.9332	4.2602	23.3122	139.9909	63.5738	18.8876	6.6957
12-16	230.2948	0.5062	3.8882	14.0482	103.5822	62.2292	27.4530	18.0099
16-20	NA							
20-24	NA							

Table C.8 GC-9 Sieve weight retained

GC-9								
Interval	Initial Weight	Sieves						
		10	18	35	60	120	230	B
(ft)	(g)	(g)	(g)	(g)	(g)	(g)	(g)	(g)
1-4	270.1176	0.0273	0.8823	10.6756	88.4745	76.3457	56.9693	36.6816
4-8	329.2138	0.0182	1.1149	13.8345	110.7068	164.2865	34.0807	4.1378
8-12	315.1877	0.0322	1.2948	12.7219	77.2156	119.8695	71.0969	32.5260
12-15	223.6120	0.0107	0.8786	14.5137	79.0292	63.2126	53.0429	12.5992
15-16	155.7824	0.0000	0.0339	0.0955	9.6455	85.0650	50.9751	8.4867
16-17	170.1947	0.0000	0.5678	15.5946	69.4603	31.5258	42.9562	9.6027
17-20	176.7672	0.0751	0.6680	22.8986	129.3332	20.9275	1.9309	0.2846
20-21	361.3180	0.4028	4.8271	44.0999	254.8930	41.8114	4.6919	2.3821
21-24	256.5585	3.7995	6.1439	30.1484	145.4752	41.1064	23.8856	5.2797
24-28	216.9504	0.0660	2.4564	61.5780	120.0785	29.9701	2.0750	0.3141
28-32	369.6886	27.0515	13.2644	103.0088	144.1621	56.0118	22.1885	2.8414
32-34	282.9343	19.2492	52.8169	123.9922	63.5095	14.2277	6.9924	1.2298
34-36	240.2162	0.1502	2.2274	32.8507	146.3905	41.8493	11.7703	4.4112
36-40	335.6789	0.0370	1.8735	38.8606	236.2506	43.7991	8.4698	5.1160
40-44	286.9229	9.2845	4.1064	52.2315	178.6494	34.3400	5.4570	2.5778
44-46	252.9644	12.4798	7.3124	45.3752	155.2341	26.6557	3.2415	2.5300
46-48	208.1028	5.0087	6.5830	52.6916	119.3602	19.6884	2.8982	2.0655
48-52	361.7466	3.0767	5.3347	61.6728	263.8485	19.2312	5.9892	3.0132
52-53	256.7863	0.4597	1.8174	10.4374	203.8971	17.5916	15.3297	7.4170

Table C.8 (Continued)

GC-9 (Continued)								
Interval	**Initial Weight**	**Sieves**						
		10	18	35	60	120	230	B
(ft)	(g)	(g)	(g)	(g)	(g)	(g)	(g)	(g)
53-54	CLAY							
54-56	262.1935	0.1086	0.0370	2.1255	233.7705	17.5330	5.6193	2.7443
56-58	152.4670	0.8672	1.2513	19.4463	112.5552	12.9778	3.6325	1.8353
58-60	221.1116	0.0192	0.1363	8.1010	197.4001	10.5120	2.8367	2.0827
60-61	242.2054	0.2170	0.4205	4.6041	211.7436	18.0211	4.2626	2.9073
61-62.5	233.9739	0.0000	0.0632	1.7271	159.8985	52.7382	13.4751	6.0696
62.5-63	CLAY							
63-64	173.9863	0.2982	0.4855	10.5059	132.8267	19.7703	6.5994	3.3335
64-68	266.7807	0.4146	3.1446	72.9367	150.6706	23.4967	10.2408	5.8645

Table C.9 GC-10 Sieve weight retained

GC-10								
Interval	**Initial Weight**	**Sieves**						
		10	18	35	60	120	230	B
(ft)	(g)	(g)	(g)	(g)	(g)	(g)	(g)	(g)
3.5-4	117.2866	0.2144	10.3436	29.8386	35.4172	21.1472	14.5098	5.4448
4.0-8	323.9363	4.0407	7.9915	81.5368	121.6830	65.1401	33.1434	9.7612
8-12	360.3611	8.6115	13.3279	87.1019	160.3724	62.5418	18.3416	9.4234

Table C.10 GC-11 Sieve weight retained

GC-11								
Interval	**Initial Weight**	**Sieves**						
		10	18	35	60	120	230	B
(ft)	(g)	(g)	(g)	(g)	(g)	(g)	(g)	(g)
1-3	285.3445	7.5679	17.3135	27.1764	119.0389	43.4877	32.8211	38.1327
3-4	CLAY							
4-8	CLAY							
8-12	CLAY							
12-16	CLAY							
16-17	271.6061	1.7678	5.007	1.8687	16.4572	207.5158	25.0783	14.8081
17-17.5	CLAY							
17.5-20	385.0166	40.5382	19.7218	20.4477	53.5205	205.3915	29.3351	17.8714
20-23	320.4539	0.8211	0.7542	0.7527	62.284	230.6474	13.5517	11.8807
23-24	199.4532	0.0117	0.0042	0.0785	3.8216	178.4147	10.607	6.8553
24-28	310.8712	0	0.0108	0.0582	27.5633	262.6197	13.7602	6.9142
28-31	188.8155	0.2493	0.1791	0.7486	28.4792	127.4	21.8493	10.1887
31-32	267.6799	0	0.1484	0.896	63.1808	165.6351	26.3163	11.6063
32-36	296.9629	0.127	0.2489	1.2166	49.2099	201.2614	32.7269	12.6538
36-40	288.314	0.0384	0.0582	0.132	38.8905	212.5776	27.5829	10.4006

Table C.11 GC-12 Sieve weight retained

GC-12								
Interval	**Initial Weight**	**Sieves**						
		10	18	35	60	120	230	B
(ft)	(g)	(g)	(g)	(g)	(g)	(g)	(g)	(g)
1-4	271.8982	0.3321	1.7095	14.3119	81.2666	101.1693	51.5199	20.9559
4-8	243.8207	0.0750	1.8114	17.2857	91.2638	87.4226	29.5313	14.0040
8-9	179.6164	0.0540	1.5215	11.5491	57.1268	72.6138	25.9513	8.7885
9-12	330.7617	18.3087	7.6455	31.2493	146.8402	97.6886	20.6755	6.0553
12-14	404.9740	7.7589	16.5750	119.9059	189.8822	55.7743	8.3029	4.7318
14-15	214.8255	52.4358	33.4690	59.5517	39.8536	17.0127	8.8714	2.3171
15-16	CLAY							
16-18	CLAY							
18-20	CLAY							
20-24	CLAY							
24-28	CLAY							
28-31.5	CLAY							
31.5-32	76.1649	0.0000	0.0224	0.1846	5.4307	22.7531	38.3130	8.9108
32-34	CLAY							
34-36	CLAY							
36-38	CLAY							
38-40	CLAY							
40-42	CLAY							
42-43.5	CLAY							

Table C.11 (Continued)

GC-12 (Continued)								
Interval	Initial Weight	Sieves						
		10	18	35	60	120	230	B
(ft)	(g)	(g)	(g)	(g)	(g)	(g)	(g)	(g)
43.5-44	CLAY							
44-45	205.4537	39.7798	4.2374	2.3318	54.9625	48.5408	42.3521	12.0972
45-46	305.1508	0.0000	0.0162	6.7123	215.5117	65.2538	11.1744	5.6220
46-48	202.0299	0.0000	0.0102	5.9537	130.6634	46.0243	12.5462	5.7963
48-52	492.7109	0.0000	0.1964	52.6718	347.6350	73.2817	12.6962	4.9663

Table C.12 GC-13 Sieve weight retained

GC-13								
Interval	**Initial Weight**	**Sieves**						
		10	18	35	60	120	230	B
(ft)	(g)	(g)	(g)	(g)	(g)	(g)	(g)	(g)
1-4	280.1522	1.4689	19.6232	87.1481	115.4585	22.8847	12.3972	18.5507
4-8	218.5001	5.0757	18.2868	72.9833	94.9436	18.6937	4.5895	3.2335
8-11.5	189.4606	7.3067	13.3618	55.8705	87.7356	19.4244	4.1983	1.6766
11.5-12	84.8657	0.4746	5.0178	35.7535	32.3724	8.2291	1.9231	0.6819
12-14	175.8876	8.1485	13.2903	59.8125	81.0008	7.8961	3.0441	2.0190
14-16	239.9830	19.6037	8.8650	38.0197	97.9541	57.5343	10.0874	7.5347
16-19	122.0329	1.2633	4.7253	24.7255	74.7967	14.3450	1.4792	0.7112
19-20	186.5038	9.5660	42.6977	90.3405	27.7544	6.6874	5.1112	3.5323
20-24	237.1898	0.1179	0.1604	0.9800	62.9357	127.7756	23.6306	20.4913
24-28	209.1609	0.0000	0.0160	0.8248	73.6901	110.1691	17.0822	6.8450
28-30	257.0776	2.7432	0.5980	6.2367	115.0373	92.0373	29.7407	10.1922
45.5-46	164.5253	0.0320	0.0605	0.3015	17.0568	96.2956	38.2140	11.9577